AN EXPERIMENTAL SIMULATION OF FIRE INSIDE AN ENCLOSURE USING PC BASED DATA ACQUISITION SYSTEM

by

ATUL MATHUR

DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

JANUARY, 1990

AN EXPERIMENTAL SIMULATION OF FIRE INSIDE AN ENCLOSURE USING PC BASED DATA ACQUISITION SYSTEM

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

by

ATUL MATHUR

to the

DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR

JANUARY, 1990

CERTIFICATE

This is to certify that the work presented in this thesis entitled "An Experimental Simulation of Fire Inside an Enclosure Using PC Based Data Acquisition System" by Mr. ATUL MATHUR has been carried out under our supervision and it has not been submitted elsewhere for the award of a degree.

Keshav Kant
Jan 3, 1990

T. Sundararajan

(T. SUNDRARAJAN)
Assistant Professor
Department of Mech. Engg.
Indian Institute of Technology
Kanpur, India

(KESHAV KANT)
Assistant Professor
Department of Mech. Engg.
Indian Institute of Technology
Kanpur, India

January, 1990.

ACKNOWLEDGEMENTS

I feel fortunate to have worked with Dr. T. Sundarajan and Dr. Keshav Kant. They were source of encouragement, direction and help, all along my association with them. I am extremely thankful to both of them for the tremendous amount of support they provided to me, at every stage of my project.

I am also thankful to Dr. Y. Jaluria, Professor, Rutgers University, USA, for his involvement in early stages of the project. It was nice of him to spare time for interactions with me during his stay at IIT Kanpur and providing me with lot of literature and some very useful ideas.

My friend, Mallikarjun, played a very cruicial role in the final stages of thesis work and finally, it was due to him, that I could finish in time.

(ATUL MATHUR)

CONTENTS

--.--

ABSTRACT

The absence of an appropriate and reliable strategy for the prevention of fire accidents in various places underlines the need to study the spreading phenomena of fire. Each incident of fire spreading has been found to have some important chracteristics peculiar to that very situation although there are some common features also among different situations. Present study aims at simulating a localized fire using a small plate heater inside an enclosure comprising of several pillars. To study the spreading pattern, transient temperature data from various locations inside the enclosure have been collected using a personal computer (XT) as a data acquisition device. An analog to digital interface card has been used to digitize the analog temperature signals from the thermocouples placed at various locations inside the enclosure. Also a flow visualisation study has been conducted for better physical understanding of the phenomena. Results of the study have been correlated with the trends shown by the analysis of temperature data. Results of the experimental investigation are presented in the form of graphs, showing the , variation in the temperature at various locations inside the enclosure with respect to time. To study the effects of various parameters such as the plate heater temperature, heater location and aspect ratio of the enclosure on the distribution of the natural convection flow are also studied.

Results of the study indicate that with a localized heat source inside the enclosure, only the top portion of the

enclosure gets affected whereas the bottom portion remains essentially unaffected. Besides this, it was seen that heater location with respect to walls of the enclosure plays significant role in deciding the flow patterns at the top. The heat of the plume originating from the heat source gets dissipated to the environment from the top of the enclosure which results in a temperature gradient with respect to distance from the source.

NOMENCLATURE

Pr	Prandtl Number
Ra	Rayleigh Number
A	Aspect Ratio
g	Acceleration due to gravity, ms^{-2}
β	Coefficient of Volume expansion, K^{-1}
T	Tmperature, K
H	Height, m
V	Velocity, ms^{-1}
t	time, s

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 GENERAL BACKGROUND

Fire, that has played a vital role in the development of our society, also has the potential of being extremely hazardous. It is responsible for a number of accidents in various places leading to loss of property and lives. The spreading of fire depends upon the geometry of the situation, apart from the arrangement of the fire source and other inflammable materials within the structure. For this reason, each fire-accident such as that inside households, highrise buildings, industrial structures or coal mine enclosures, exhibits important differences as compared to other situations, although there are some common features in all these fires. The present study focuses attention on the behaviour of fire inside an enclosure. The enclosure considered here is rectangular in shape and is insulated from all sides. It consists of pillars which support the roof and also serve as obstructions that alter the direction of spreading of fire. A small plate heater inside the enclosure represents the fire. The endeavour is to analyse the spreading patterns inside the enclosure by collecting transient temperature data at various locations.

This study is applicable to two major situations, namely, the coal mine fires and the building fires. In both the cases, the spreading of fire is governed by natural convection flow and heat transfer through connected pathways/compartments. A

feasible and reliable fire control strategy for these situations needs a proper understanding of the spreading phenomenon. Although fire has shown a consistent way of spreading inside the buildings, it has been a problem to keep unaffected parts of the building isolated from the fire hit zone. In case of coal mines, where fire hit zones are sealed, the process of spreading is a very complex one due to the complicated configurations of mines. Although this study has considered a much simpler geometry, it is a step forward towards the understanding of the above mentioned phenomena.

The present study is fully experimental in nature and involves the usage of a personal computer for data acquisition. Transient temperature data acquisition has been achieved using an analog to digital (A/D) interface card inside the personal computer (PC-XT). Digital data acquisition, besides being very fast, is also less prone to noise. Also, to strengthen the signal being supplied to the computer (so that the signal to noise ratio can be enhanced) reference junctions of the thermocouples were maintained at $0^{o}C$ within an ice box. The effects of heat source location, heating level and the enclosure aspect ratio upon the transient development of the temperature field have been presented. For greater physical understanding of the flow phenomena, a flow visualisation study has also been conducted and has been correlated qualitatively with the temperature measurement.

1.2 LITERATURE SURVEY

Study of fire inside an enclosure with pillars is relatively new as most of the studies in this field have concentrated on simple geometries such as rectangular or cylindrical enclosures without obstructions inside. Also in most of the previous work, the entire surface of one or more walls of the enclosure has been maintained at temperatures above or below that of the ambient. The present study pertains to the phenomenon of spreading of hot gases from localised heat source placed on the floor of the enclosure, leaving most part of the bottom surface unheated. Although, studies related to similar enclosure and heater configurations are not available in the literature, a few research works have been carried out on the spreading of fire in buildings and mine configurations. Also fundamental studies upon the spreading characteristics of plumes, jets or other buoyancy driven flows inside rectangular enclosures with no obstructions, are available. A brief review of literature in the areas of coal mine fires, building fires and natural convective flows within enclosures is presented below.

One of the pioneering works in the area of natural convection in enclosures with localised heating from below, is that of Torrance et al. (1969). They conducted an experimental investigation of steady state natural convection induced by a small hot spot centrally located on the floor. Enclosures of rectangular and circular floor plan were employed with height equal to one half of the major dimension of the floor. The flow patterns showed similarity in both the cases with a column of heated air rising above the hot spot

and impinging against the ceiling. The impact forms a wall jet along the ceiling which spreads out radially and turns downwards when it reaches the vertical wall. The air then turns inward and moves toward the centre to get entrained once again in the rising column. During the course of circulation, the flow described a symmetrical vortex motion on both sides of the column. Also it was found that as the temperature is raised, these symmetrically located vortex centres were flattened against the ceiling and elongated.

Nansteel et al. (1981) experimentally investigated natural convection in a two dimensional rectangular enclosure fitted with partial vertical divisions. The horizontal walls were adiabatic while the vertical walls were maintained at different temperatures. The experiments were conducted with water (Pr = 3.5), for a range of Rayleigh number $2.3\times10^{10} \leq Ra \leq 1.1\times10^{11}$ and an aspect ratio of A = 1/2. The experiments revealed the existence of three relatively distinct regions at Ra approaching 10^{11} : i.e. the existence of an inactive core region, a region of very weak recirculation and a peripheral boundary layer flow. The partial divisions were also shown to significantly decrease the overall heat transfer, especially when the partitions were non conducting.

Gnafakis and Manno (1989) experimentally studied transient destratification in a rectangular air filled enclosure. They found that destratification of an enclosure involved fairly complex thermal flow phenomena even for cases of relatively mild deviations from idealized geometries and conditions.

The problem of rectangular enclosures with either two

horizontal or vertical walls maintained at different temperatures has received much attention due to its application to solar collectors, thermal insulation using air gaps, solar ponds etc. Interest has been primarily focussed upon knowing the resulting heat transfer and flow characteristics and special attention has been paid to the thermal stability aspects and the onset of natural convection within the gap. Experimental as well as numerical investigations are available which shed light on the above mentioned aspects. The experimental study by Eckert and Carlson (1961) for air and that by Elder (1965) for silicon oil of ($Pr \simeq 1000$) have significantly contributed to the understanding of flow and heat transfer mechanisms in vertical rectangular cavities. In the first study, the aspect ratio was varied over the range 2.1 to 46.7 and the Rayleigh number was varied from 200 to 2×10^{5}. At low values of Ra, conduction was dominant in the air between the two walls and a linear temperature distribution was observed. At large Ra, boundary layers developed on the vertical surfaces and the core region was linearly and stably stratified. Elder (1965) used silicon oils of $Pr \simeq 1000$ and varied the aspect ratio from 1 to 60. Rayleigh numbers considered were upto about 1×10^{8}. At Ra less than about 1000, a weak steady unicellular circulation was observed, with fluid rising near the hot wall and descending adjacent to the cold one. This corresponds to conduction regime of Eckert and Carlson (1961). For $10^{3} \leq Ra \leq 10^{5}$, large temperature gradients occurred near the walls and a uniform vertical gradient in the interior region was observed. Turbulence arose around $Ra = 1 \times 10^{9}$, at about half the height

in the cavity and then spreaded to the ends at higher Ra. Among the earliest measurements of natural convection heat transfer in horizontal cavities, were those of Soberman (1958), Silveston (1958) and Globe and Dropkin (1959).

The walls of an enclosure play a very significant role in the enclosure fires. Jaluria (1986) highlighted the mass, momentum and energy transport as a consequence of wall jet flows by carrying out an integral analysis. At the very early stages of the fire, the walls remain essentially unheated and remain at the initial temperature that existed before the onset of fire, whereas a hot upper zone of gas overlying a cooler lower zone, results from the flow induced by the fire plume. Due to this temperature difference between the walls and gases in the upper layer, a downward flow is generated adjacent to the cooler upper region of the wall. This buoyancy driven flow is discharged into the lower zone, across the interface. It becomes upwardly buoyant in the lower layer and rises toward the interface to cause greater mixing in the lower zone and thus, affecting the transport between the two zones, across the interface.

Although the modelling of air cooling of collieries was considered as early as 1951 and other similar problems were investigated from time to time, advances in mine fire fighting technology have been rather slow to come by as observed by Karnavas and coworkers in 1982.

A one dimensional, transient simulation of the flow of air and fire gases in complex ventilation networks is discussed by Waclawik and Branny (1986). The ventilation network is considered to be made up of many flow branches with

common junction points. The velocity, pressure, temperature and density of the ventilation air flow under steady conditions are predicted using an iterative numerical procedure. A one dimensional transient study of heat exchange between the air flow and the rock mass has been attempted by Stephanov et al. (1983). The solutions have been predicted by the Laplace transformation technique and the numerical method of planned volumes. This work is an improvement over the earlier studies on the same problem by Kremnev and Juravlenko (1978) and Stephanov (1983). A one dimensional transient calculation of heat and moisture transfer in the partly wet airways of a mine ventilation system has been performed by Starfield and Bleloch (1983. It appears from a survey of the mine fire literature that modelling work in this area still needs considerable amount of development.

In building fire research and other related areas many recent advances have taken place. The effects of wall flow of hot combustion gases in the early stages of fire growth in compartment fires have been analysed (Jaluria, 1984; Kooper and Jaluria, 1988). Through an integral analysis, they have highlighted the roles played by the negatively buoyant wall flow and the thermal plume above fire, in the establishment of two distinct zones (a hot upper layer and a cold bottom layer) inside the room. The authors have also made temperature and velocity measaurements in an enclosure set up using thermocouples and a hot wire system. The data were acquired with the help of a PC based data acquisition unit and processed on a mainframe computer to test the analytical model. The authors also performed flow visualization studies

by injecting a jet of kerosene smoke into the enclosure. Their theoretical model and experimental measurements indicated close agreement.

The heat transfer process between the buoyancy driven flow of hot combustion gases and the ceiling wall of an enclosed chamber, was experimentally investigated by Zukoski (1987). The author provided a detailed discussion regarding the nature of gravitational instabilities between the hot and cold layers inside the room. The experiments were carried out with the help of a microcomputer based data acquisition system and a series of thermocouples. Quintiere (1981) theoretically analysed the problem of wall fire spreading using the two zone methodology for the gas phase. The rate of burning and the fire spread along the vertical surfaces were shown to depend on the incident radiative flux and the local oxygen concentration. Expressions for these functional dependencies were suggested for incorporating them into a wall flame model. The effects of room openings on fire plume entrainment were discussed by Quintiere et al. (1981). Apart from temperature and velocity measurements inside a laboratory scale set up, the authors also performed a one dimensional, steady plume analysis following the formulation of Hoult et al. (1969). A comprehensive theoretical model including various heat transfer contributions for home fire was proposed by Emmons (1978).

The analysis of multi compartment fires was carried out by many authors. Cooper and coworkers (1981) conducted smoke visualization studies along with temperature and velocity measurements to observe the interaction between several

compartments through a corridor.

Theoretical simulation of the multi room problem was attempted by (Rockett, 1982; Ramsdell, 1981; Rockett,1985). A comparative study of the available software codes was discussed by rockett and Morita (1985). The application of such a software code to a silver mine fire was illustrated by Rockett (1985).

1.3 SCOPE OF PRESENT STUDY

The principal goals of the present study are enlisted below:

1. Establishing a laboratory scale experimental facility to study the buoyancy driven flows inside an enclosure consisting of several pillars.
2. Simulation of localized fire by using a small plate heater and acquiring transient temperature data at various locations inside the enclosure for different heating levels, heater locations and aspect ratio of the enclosure.
3. Carrying out flow visualisation to observe the flow patterns qualitatively.
4. Understanding the phenomenon of spreading of fire by analysing the results of above experimentation.

During the execution of the experimental investigation certain practical di fficulties arose which placed limitations on the scope of the measurements performed and the range of variation of the parameters. The limitations are:

(i) The enclosure has been made of Perspex for the ease of

flow visualisation. Perspex becomes soft and tends to melt around $100^{\circ}C$. This restricted the heater temperature to about $200^{\circ}C$, beyond which portions near the heater had the danger of getting deformed. The duration of a single run of the experiment also had to be curtailed to about 10 minutes. Fortunately, however, the temperature field within the enclosure approaches a steady state within this time limit.

(ii) The analog to digital interface card used with the computer has only 7 channels and in a single run of the experiment, only seven out of the total eighteen thermocouples could be connected to it. For rest of the thermocouples, the experiment had to be repeated, thus requiring three runns for a single set of parameters. Since considerable amount of time had to be provided between each run of the experiment, the range of variation in the input conditions had to be limited. Therefore, only four heater positions, three heating levels and two aspect ratios were considered in the study.

(iii) In the absence of a precise temperature controller, the heater temperature ~~was~~ maintained at the desired value by manually varying the voltage supplied to it using a variac. This resulted in a variation of about $\pm 2^{\circ}C$ around the desired temperature of the plate.

(iv) An attempt was made to measure the flow velocities at various locations within the enclosure using a pitot tube and a digital manometer. However, as the velocities were too small, (an estimate using $v \sim g\beta TH$

gives velocities of the order of 30 cm/s. They were beyond the range of measurement of the available manometers. Hot wire anemometry was not considered for velocity measurement due to the extensive correction procedure to be applied in order to account for the non isothermal nature of the flow. Also inserting the hot wire probe inside the enclosure of the present study proved to be very incovenient.

(v) Although flow visualization was performed to observe the flow patterns for various input conditions, they could be photographed with clarity of flow details, using the photographic equipment at our disposal. For this reason, the observed patterns (which were extremely clear to the naked eye) were recorded in the form of manually drawn sketches.

With the above limitations, an extensive amount of temperature data have been collected to analyse the transient development of the temperature field within the enclosure.

1.4 ORGANIZATION OF THESIS

The thesis has been organised in the following manner:

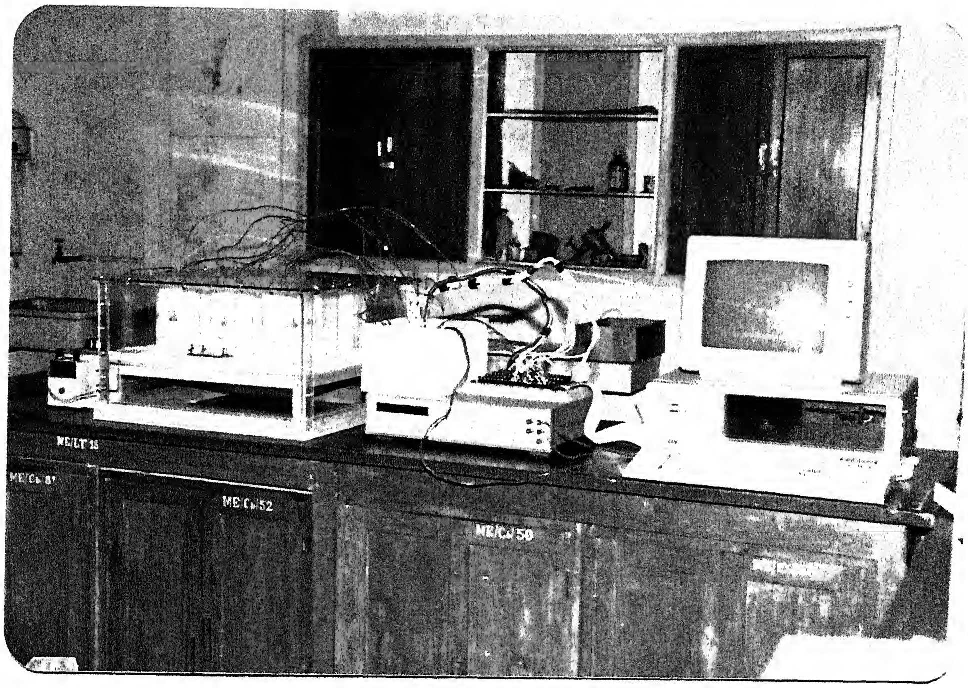
Chapter 2 contains the details of the overall experimental setup and its individual components. Chapter 3 contains the detailed experimental procedure, estimated errors in the measurements and the discussion of results obtained.

Chapter 4 summarizes the conclusions derived from the present investigation and indicates the directions for future research on the problem studied here. This is followed by a list of references.

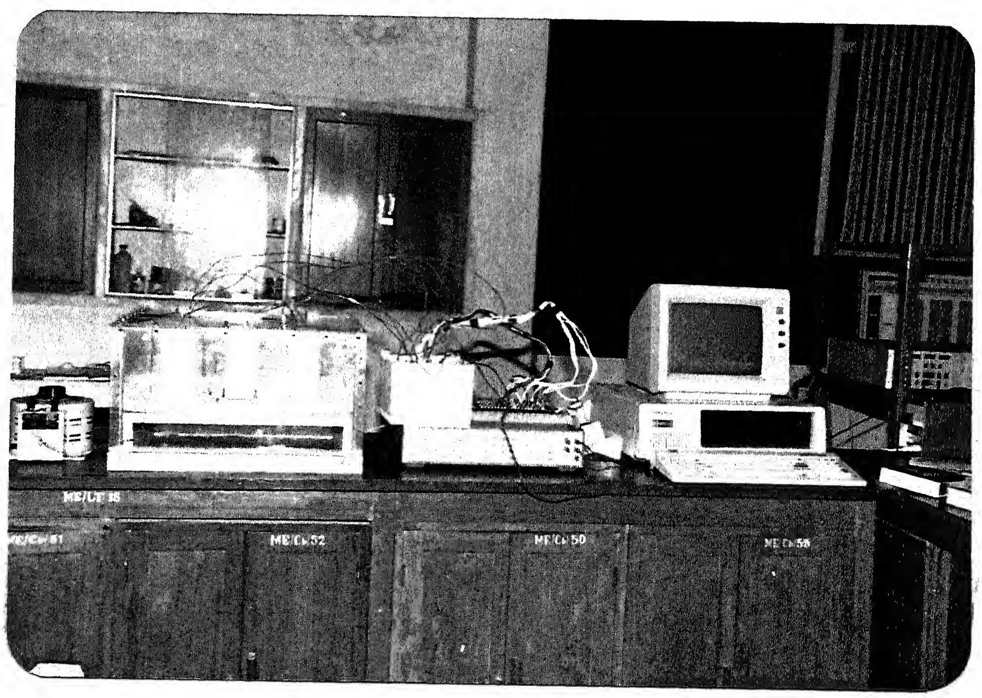
CHAPTER 2
EXPERIMENTAL SETUP

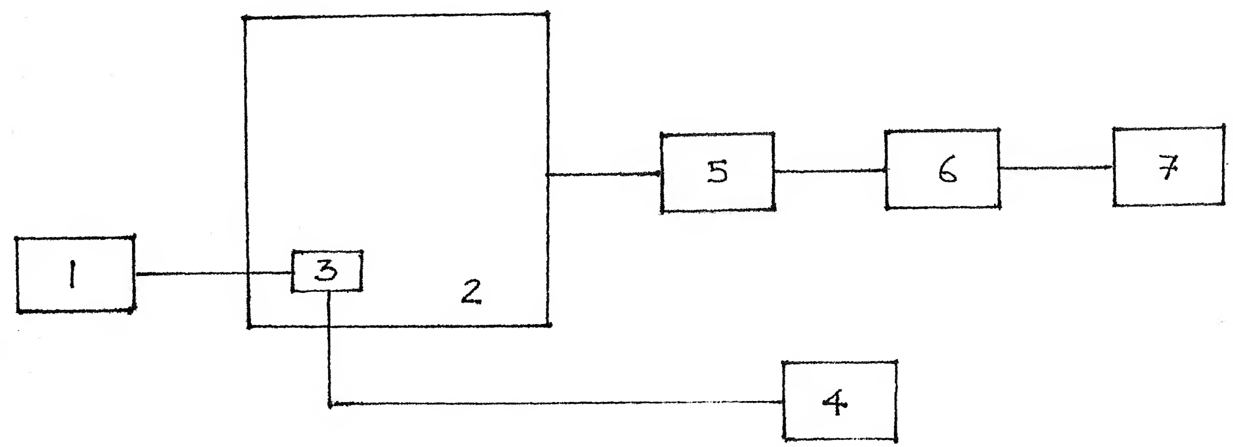
2.1 COMPONENTS OF THE EXPERIMENTAL SETUP

The most important component of the experimental setup is the insulated rectangular enclosure which includes several pillars supporting the roof. Thermocouple probes have been introduced into the enclosure at various locations through holes drilled on the sides of the pillars. The non beaded ends of the thermocouple wires are submerged into an ice box containing water ice mixture, in order to maintain reference junctions at $0^{o}C$. The heat source is a plate heater assembly which can be placed at different locations on the floor of the enclosure. The power input to the heater can be controlled manually with the help of a variac and the plate temperature is monitored by connecting the output of a thermocouple probe embedded in the plate, to a 6 and 1/2 digit millivoltmeter. Leads from the reference junctions are connected to the terminal panel which in turn is linked to an A/D interface card. The A/D card is plugged into the PC, thereby enabling the PC to act as a high speed data acquisition unit. Photographs on the next page show two different views of the complete experimental setup. Also a schematic representation of the assembly of various components of the setup is shown in Fig. 2.1. The main constituents of the setup are described below.



EXPERIMENTAL SETUP





1 VARIAC

2 ENCLOSURE

3 HEATER

4 MILLIVOLTMETER

5 ICE BOX FOR REFERENCE JUNCTIONS

6 A/D CARD

7 PERSONAL COMPUTER

FIG. 2.1 SCHEMATIC REPRESENTATION OF THE SETUP

2.11 ENCLOSURE

The enclosure is the test cell inside which the spreading of hot gases originating from a heat source has been analysed. It is rectangular in shape and is closed from all sides. The overall inside dimensions of the enclosure are: length = 490 mm,breadth = 490 mm and height = 240 mm or 160 mm.

Except the bottom, all the other sides of the enclosure are made from 6 mm thick Perspex sheets. Perspex has been chosen as the material because it is transparent enough to conduct flow visualisation studies. The bottom of the enclosure is made up of a 19 mm (3/4") thick thermocole slab placed on the top of a 6 mm thick plywood sheet. The test cell contains nine pillars which span the entire height of the enclosure starting from the bottom. These pillars are also made of Perspex and along the vertical direction, each pillar can be split into 3 equal parts if required. This feature has been introduced to facilitate variations in the aspect ratio of the enclosure. All the pillars have 2 mm dia holes drilled on all the faces at various heights. Thermocouple probes can be inserted into the enclosure through these holes.

All the four side walls and the top of the enclosure are insulated with 6.35 (1/4") thermocole sheets. Also the pillars are similarly insulated from inside adjacent to the interior surfaces of their Perspex walls. The idea behind insulating all the surfaces is to simulate the low thermal conductivity conditions arising in the case of building and coal mine fire situations.

Appropriate recesses have been provided on the floor of

the enclosure to accommodate a plate heater assembly. By covering the recesses which are not in use by suitable sheets of asbestos, conditions have been simulated which correspond to the placement of a plate heat source in level with the floor of the enclosure. The heater element can be housed at four different locations adjacent to the front wall, as shown in Fig.2.2

2.12 THERMOCOUPLE PROBES

Chromel-Alumel thermocouples(K type)of 24 gage size were used as probes for temperature measurement. There were totally eighteen thermocouples,placed at various positions inside the enclosure as shown in Fig. 2.3.

Prior to their use, the thermocouples were calibrated with the help of a hot oil bath which was used to maintain different temperatures. The temperature of the oil was measured with the help of an accurate thermometer whose least count was $0.1\,^{o}C$. A 6 and 1/2 digit millivoltmeter was used for the measurement of voltages generated across the thermocouples. During calibration of each thermocouple, the reference junction was kept at $0\,^{o}C$. It was found that the voltage temperature characteristics of individual thermocouples were very close to one another. The thermocouples were calibrated at 5 different temperature. The averaged calibration curve or the voltage temperature characteristic shown in Fig. 2.4 of the thermocouples was used for converting the voltage data (from the experiment) into temperature.

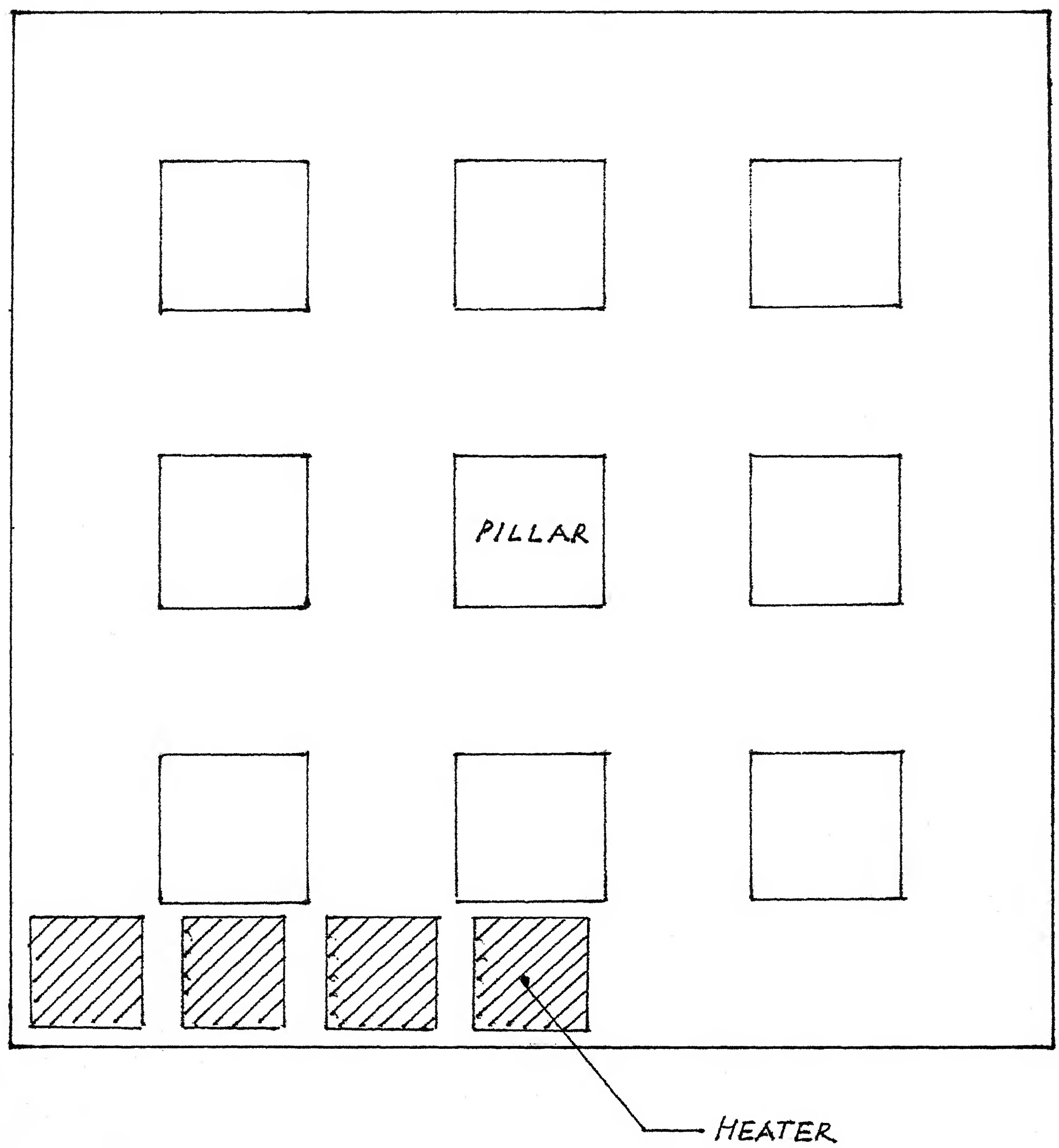


FIG 2.2 TOP VIEW OF THE ENCLOSURE SHOWING HEATER LOCATIONS

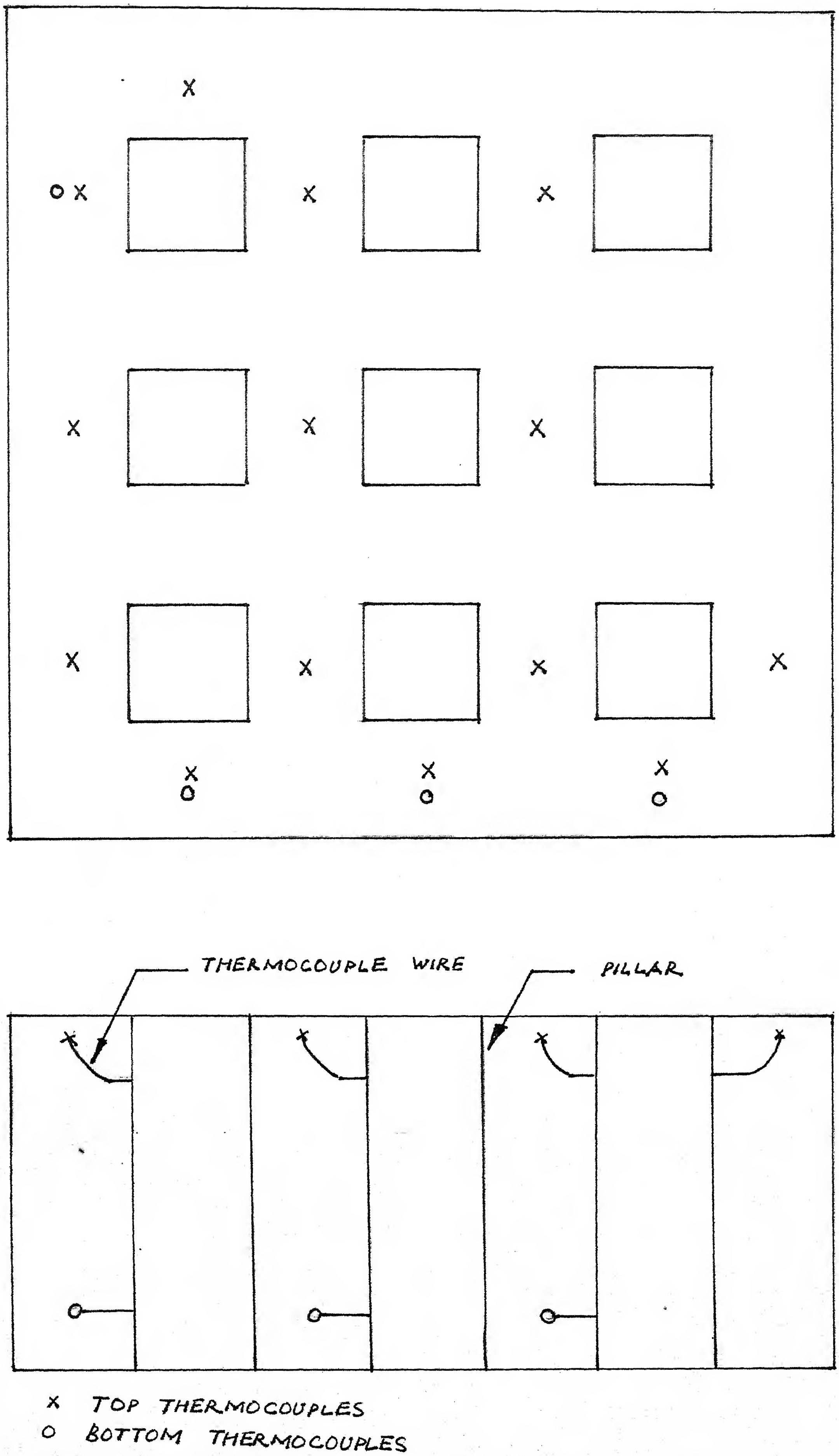


FIG 2.3 THERMOCOUPLE PROBES INSIDE THE ENCLOSURE

THERMOCOUPLE CALIBRATION CURVE

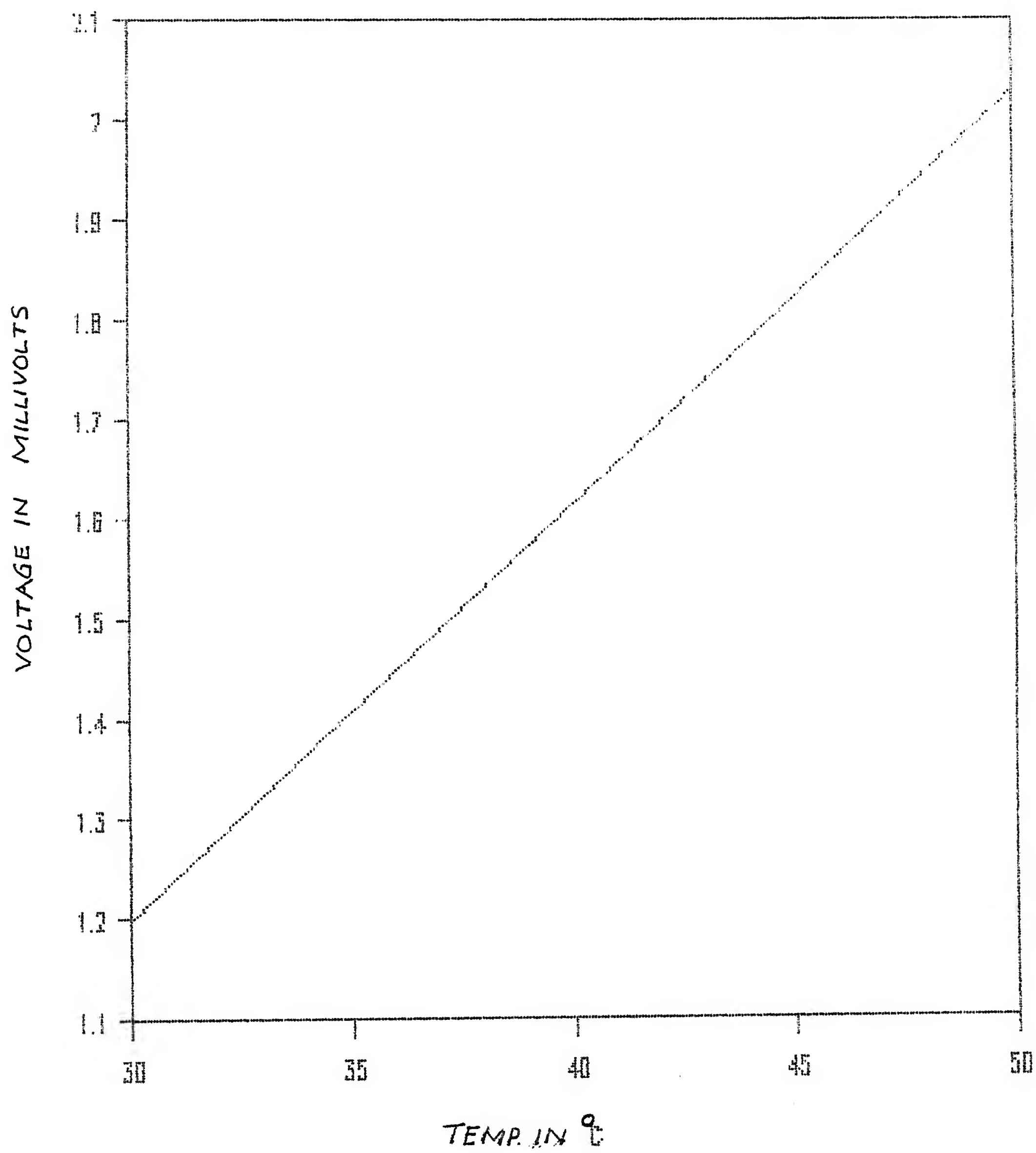


FIG. 2·4

2.13 REFERENCE JUNCTIONS AND ICE BOX

In order to maintain a constant temperature at the thermocouple reference junctions, they were submerged in an ice water mixture. An ice box made of thermocole was used for this purpose. The unbeaded ends of thermocouple wires formed their reference junctions at the strip connectors from which copper leads were taken to the A/D interface card. Ice was smashed into fine particles and was allowed to melt partially before its use in the ice box.

2.14 HEATER ASSEMBLY

A plate heater assembly was fabricated to serve as a plume heat source representing the fire in an actual situation. It was made into an assembly containing a heating element so as to have a large thermal capacitance, which will in turn, dampen fluctuations of plate temperature. The heater of an electrical iron box was used for this purpose whose maximum wattage was 450 W. The heating element consisted of a Nichrome wire placed between two mica sheets. This heater was, in turn, sandwitched between a 2 mm thick metallic plate on the top and an asbestos sheet at the bottom. The heater was provided power through a variac and its temperature was monitored by inserting a thermocouple between the top metallic plate and the heater. This thermocouple was connected to a digital millivoltmeter and the temperature was controlled by varying the input power through the variac.

2.15 HIGH PRECISION MILLIVOLTMETER

A high precision millivoltmeter was used to monitor the temperature of the heater. Thermocouple leads from the heater were connected to this instrument and by observing the voltage shown on its display, the temperature of the heater was controlled by manually varying the voltage across the heater. The millivoltmeter had the following specifications:

Model: HP 3457, manufactured by Hewlett-Packard, USA

Verastility: (i) Hewlett–Packard Interface Bus (HP‾IB) system,

(ii) Bench applications

Maximum input current: 1.5 amps from 250 Volt source

Maximum input voltage: +450 V peak

Range : 30 mV, 300 mV, 3.0V, 30.0 V, 300.0 V

Accuracy : 6 and 1/2 digit.

2.16 A/D INTERFACE TO PC

The outputs of the thermocouples were analog voltage signals of the order of 1 mV. These signals were supplied to an analog to digital interface card which digitized as well as amplified the signals. Following are the main specifications of the interface card:

Model : DT 2805, analog and digital I/O board

A/D Resolution: 12 bits

A/D Thruput : 6.0 kHz

Maximum gain : 500

Number of A/D Channels : 8 (One channel is exclusively for ambient temperature compensation).

The interface DT 2085 is a plug in type card which can be used with any IBM compatible personal computer. It can be plugged into any one of the expansion slots of the computer. This card can be programmed from the personal computer itself to perform the analog to digital conversions. A real time software package named PCLAB (SP0141) is available for use with the DT 2805 card. This package has capabilities to acquire input voltage signals, digitize them and amplify them in order to overcome the noise inside the computer. Finally the digitized data are also stored in a user defined file.

Amplification gain of the card is user selectable and it can be one of the four levels viz, 1, 10, 100 and 500. The card has the requirement that the input signal be between 0 to 10 V. In the present case, since the signals from the thermocouples were of the order of 1 mV, maximum gain of 500 was used. Also to boost up the signals further, an external amplifier was initially used with a gain of 100. Although the results with external amplifier were fairly reasonable in terms of reduction in the noise/signal ratio, the amplifier was found to suffer from zero errors (ground voltage level). Also the external amplifier gain, had to be calibrated over the range of voltages of the experiment, as it had a continuously variable gain from 0 to 300. An alternative was found to avoid the use of this external amplifier and still have reasonably strong signals, by using an ice junction with the thermocouples. This proved to be an effective way of boosting signals. The signal transformation from analog to

digital mode can be seen as consisting of the following steps:

1. The analog multiplexer chooses one input channel from those connected to the board. Since seven channels were used, it goes in a sequential fashion starting from channel 1 to channel 7 and then comes back to 1.
2. The programmable gain amplifier buffers the analog input and may increase its voltage depending on the gain setting of the board.
3. A sample and hold circuit acquires the selected analog signal from the multiplexer and stores it on a capacitor, keeping the signal voltage constant so that an accurate A/D conversion can occur.
4. Finally, the A/D converter translates the analog signal held by the sample and holds into a digital code.

For each thermocouple, temperature data were acquired at an interval of 1.05 seconds upto a total duration of 630 seconds.

2.2 USE OF PERSONAL COMPUTER AS A DATA ACQUISITION SYSTEM

An IBM compatible personal computer (XT) was used as a data acquisition device in the present study. With a suitable interface card and software, the PC can become a very powerful data acquisition and processing device. The rates of acquisition and real time processing with the help of a PC far exceeds those possible by other devices. In the present case, the software used was PCLAB (SP0141) and the interface card was model DT 2805 analog and digital I/O card, manufactured by Data Translation Inc.,USA. All the data acquired in the experiment were processed on the PC itself. The only apparent disadvantage of performing digital data acquisition with a PC

was that weak input signals tend to get corrupted with the electronic noise inside the PC. However, this disadvantage could be readily nullified by amplifying the input signal externally by some method as was done in the present experiment.

Voluminous amount of transient temperature data were acquired at various locations within the enclosure, for different heating levels, heater locations and enclosure aspect ratios. These data were plotted with the help of the PC software package LOTUS1-2-3. The plotted results along with the discussion of the observed phenomena are presented in the next chapter.

CHAPTER 3

EXPERIMENTAL MEASUREMENTS AND DISCUSSION OF RESULTS

3.1 EXPERIMENTS PERFORMED

In order to achieve the goals envisaged for the project, the following procedure was adopted during the experiments.

1. Eighteen thermocouples were placed in all, at various positions inside the enclosure. Considering the limitation that only seven thermocouples could be hooked on to the analog to digital interface card, these were classified into three groups viz. A, B and C and the separate runs of the experiment were performed to collect the temperature data for all the three groups, for a given set of input conditions. This grouping of thermocouples is shown in Fig.3.1.
2. The parameters considered in the experiment were:
   a. Four different locations of the heater adjacent to the front wall of the enclosure were considered in order to study the effect of heat source location on the distribution of the flow.
   b. Heating Level: During an experimental run,the heater was maintained at nearly a constant temperature (within $\pm$ 2 ^{o}C). Readings were taken at three different plate temperatures viz. 150 ^{o}C, 175 ^{o}C and 200 ^{o}C.
   c. Aspect Ratio: The experiments were performed for the aspect ratios of 0.33 and 0.49.

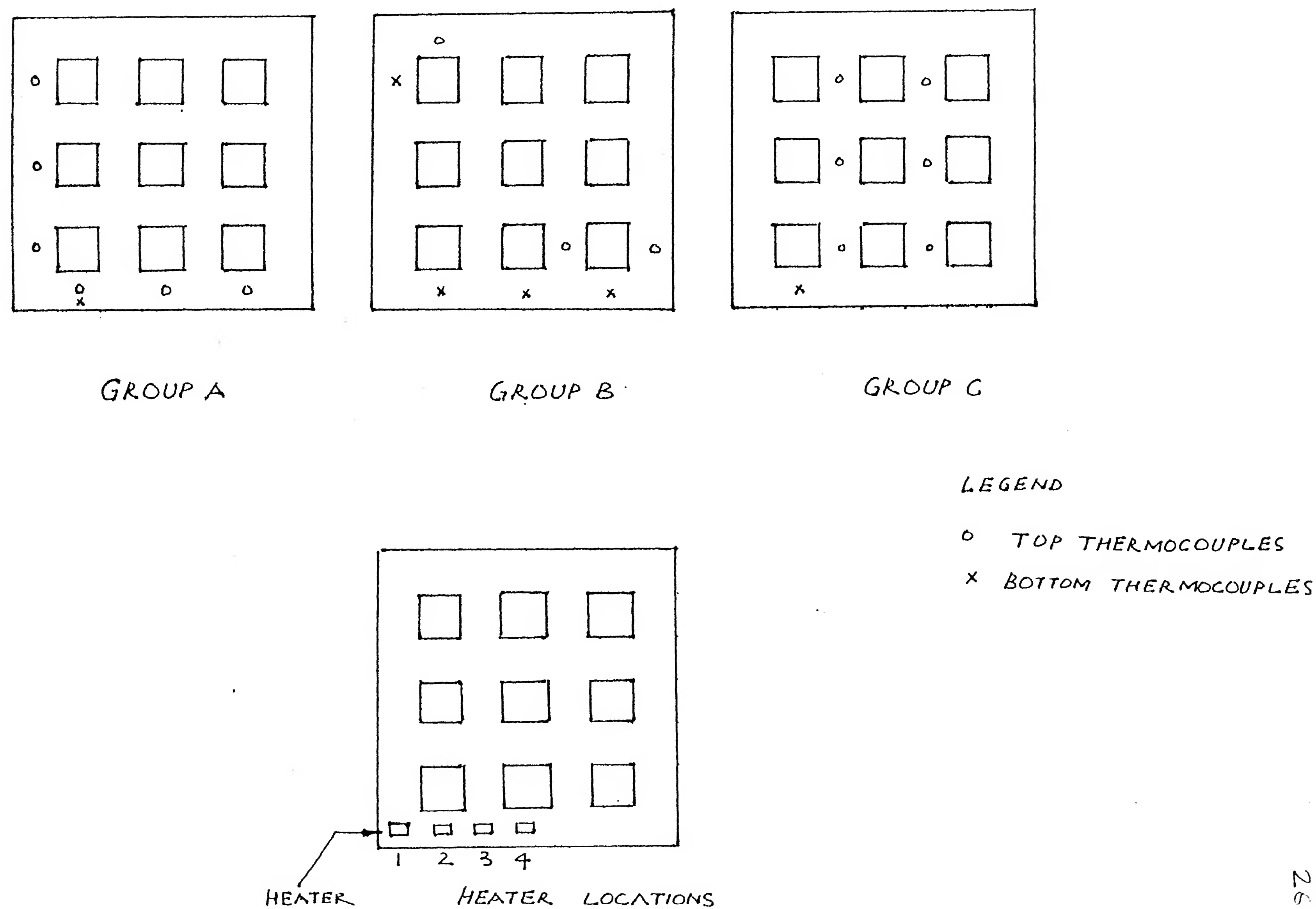


FIG. 3.1 GROUPING OF THERMOCOUPLES AND HEATER LOCATIONS

After selecting a set of parameters, leads from one of the three thermocouple groups were connected to the A/D card.

3. After placing the heater at the desired location, the heater assembly was allowed to approach nearly a steady state around the required temperature value. However, with the help of a small wooden channel, the buoyant plume was prevented from entering the enclosure during the transient heating of the heater. One of the side walls of the enclosure was kept open during this transient period and the plume was diverted outside the enclosure by the wooden channel. This arrangement ensured that the experiment was effective conducted under the conditions of constant plate temperature.

4. After executing the above mentioned procedure, any other small fluctuations in the plate temperature around the specified value were neutralised by slight manual adjustments in the power input to the heater, with the help of a variac.

5. For maintaining the reference junctions of the thermocouples at $0^{o}C$, an ice-water mixture was prepared by smashing the ice into fine particles and allowing it to melt. This mixture was kept in an ice-box and thermocouple reference junctions were submerged into it.

6. The programme for the acquisition of temperature data was run on the computer which activated the interface card to collect data from the thermocouples. Data were collected at a frequency of 6.7 readings/second for a

total duration of 630 seconds.

7. Data were stored in data files on the computer for subsequent processing.

8. The above steps were repeated for different groups of thermocouples and a set of parameters. In all, 48 sets of readings were collected which occupied the memory space equal to 24 floppy diskettes.

9. For carrying out the experiment at various input conditions, the following changes in the setup were necessitated:

   a. Change in the thermocouple connections to the A/D card, b. change in the heating level and heater location, c. change in the aspect ratio of the enclosure.

In order to minimise the time involved in making the above mentioned modifications, a systematic way of changing the input conditions was evolved. It was observed that the ice_water mixture could be maintained effectively for as many as twelve runs of the experiment. Considering this aspect and the relative ease of alterations for the various conditions, the changes were effected in the following manner:

(i) Data were first acquired for a particula r group of thermocouples, for all the heating levels and heater locations. This resulted in 12 sets of readings.

(ii) Then, the connections to the A/D were changed and another group of thermocouples was connected. Again 12 sets of readings were taken for different heating levels and heater locations.

(iii) After completing the readings for all the groups with

one aspect ratio, the height of the enclosure was changed by removing one of the three equal divisions from all the pillars. This was done in the end because it involved the opening up of the enclosure, the removal and re-insertion of the thermocouples and the change in the height of the pillars. This was the most time consuming step of all the changes mentioned above. With a new aspect ratio, readings were taken following the procedure described in steps (i) and (ii).

10. The stored data were processed first by sorting out the readings for individual thermocouples and then converting the acquired voltage data into corresponding temperatures using the calibration curve of the thermocouples. Subsequently, graphs of temperature versus time were drawn for individual thermocouples using the Lotus 1-2-3 software package.

11. Finally, flow visualisation was performed by introducing smoke generated by a bunch of mosquito coil pieces right above the heater. The smoke clearly indicated the path of the plume generated by the heater.

3.2 AN ESTIMATE OF EXPERIMENTAL ERRORS

The possible errors in the measured data at various stages of the experiment and the deviations of the input conditions from their ideally desired values, are estimated below:

1. Thermocouple calibration error: The maximum error induced was of the order of 0.6^{o}C. This error was the sum total of the least count of the thermometer used for

measuring the oil temperature, fluctuations in the readings of the millivoltmeter connected to the thermocouple, temperature shift in the ice–point from the assumed value of $0^{o}C$ and the use of averaged thermocouple calibration curve for determining the corresponding temperatures.

2. Ice point error: During a run of the experiment the errors at the reference junctions of the thermocouples were about $0.5^{o}C$. This was due to the use of ordinary tap water for making ice. The above mentioned estimate was arrived at comparing a few readings obtained with the use of demineralised water.

3. Repeatability error: This occurred as the experiment had to be repeated three times for the same set of parameters due to the limitation of channels on the A/D card. Along with this, there were other errors due to the manual control of the heater temperature (within $\pm 2^{o}C$). These errors, however, were difficult to estimate precisely since the flow characteristics of the rising plume seemed to be affected by even minor deviations or asymmetries in the input conditions, as indicated by the flow visualisation studies.

4. Error due to the heating of perspex: During a run of the experiment the perspex walls were storing energy, which was dissipated in the subsequent run of the experiment due to thermal inertia. The error was estimated to be about $1^{o}C$, although a sufficient interval of about 45 minutes was kept between any two consecutive runs of the

experiment. This error was estimated by comparing the temperatures at various locations inside the enclosure at the start of the experiment for two consecutive runs. Combining all the above errors and some other minor effects such as the changes in the ambient conditions, the estimated error involved was of the order of 2^{o}C. The actual error, however, will be smaller than this value.

3.3 ORGANIZATION OF RESULTS

Results of the experimentation are presented in the form of graphs, representing the transient variation of temperature within the enclosure. Each graph corresponds to a particular set of parameters and shows the variation of temperature of a particular thermocouple over a span of 630 seconds. At time t=0, the temperature of the entire enclosure is nearly uniform, and is equal to ambient value.

For the purpose of illustrating certain important features of the spreading phenomenon, an appropriately selected set of graphs have been clubbed into a single figure, with a maximum of six graphs per figure. This form of presentation has been preferred over the superposition of graphs into a single figure, in order to preserve the clarity of details. To facilitate understanding, a top view of the enclosure, showing the positions of the relevant thermocouples and the heater location is provided for each figure. Besides this, each graph has a 4 or 5 character code, which specifies the input parameter set and the thermocouple under consideration. The characters of this code have the following

meaning:

1. First character from left: This is a letter which may be A, B or C. It represents the group of seven thermocouples to which the particular thermocouple under consideration belongs. The scheme followed for forming the A, B or C groups is shown in Fig. 3.1.
2. Second character: This is a digit which specifies the location of the heater. Four heater locations have been considered which are denoted by 1,2,3 or 4. These heater locations are also indicated in Fig.3.1.
3. Third character: This is a letter which specifies the heating level. The plate temperatures of 150^{o}C, 175^{o}C and 200^{o}C have been considered in the present work and are represented by the letters L, M and H respectively.
4. Fourth character: This specifies the number of thermocouples within each group, A, B or C. It essentially is the indicator of the location of a thermocouple within a particular group.
5. Fifth character: This is an asterisk (*) used to denote the runs corresponding to the lower aspect ratio of 0.33. For the higher aspect ratio of 0.49, the overall code of the graph contains only four characters. The results obtained are discussed in the following sections.

3.4 TEMPERATURE DISTRIBUTION WITHIN THE ENCLOSURE

Figs. 3.2(b) to 3.5(b) show the transient variation of temperature at representative locations both near the top and

the bottom walls of the enclosure. The locations of the thermocouples and the heater for the graphs plotted in each figure have also been included for reference. It is observed from the figures that regardless of the heater location, heating level or aspect raatio, the thermocouples placed at the top level register significant rise in temperature as compared to the thermocouples at the bottom level. The rise in temperature is rapid in the beginning and then it slows down. The thermocouples at the bottom level hardly record any change in temperature (as long as these thermocouples are not directly above the heater).

The graphs clearly indicate that larger the horizontal distance between the thermocouple and the heat source, the smaller the rise in temperature. This gradient in temperature with respect to horizontal distance from the heat source implies that the heat loss mechanism through the top wall of the enclosure plays an important role in deciding both the heat transfer and plume characteristics.

It is also observed from the graphs that the time duration for the initial transient, depends upon the location of the thermocouple. For instance, thermocouples situated closer to the heat source show initial transients of smaller duration as compared to the thermocouples situated farther away. This can be explained in terms of the facts that the plume of hot gases will affect the thermocouples situated closer to the heat source earlier and for the same reason the thermal transients through the wall will, reach quasi-equilibrium conditions earlier at locations which are closer to the heat source. This conjugate heat transfer between the

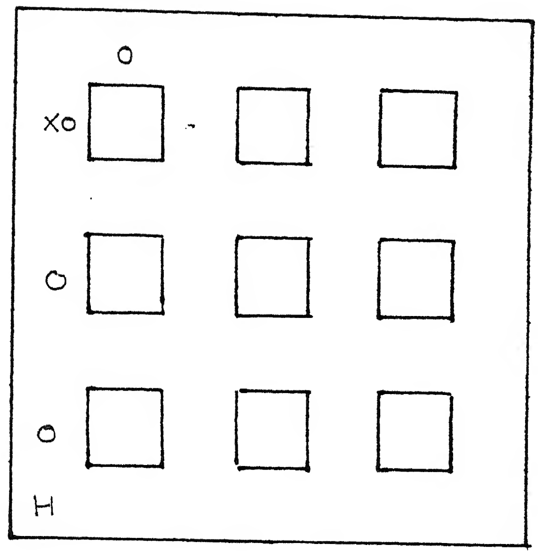


FIG. 3.2(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG 3.2(b)

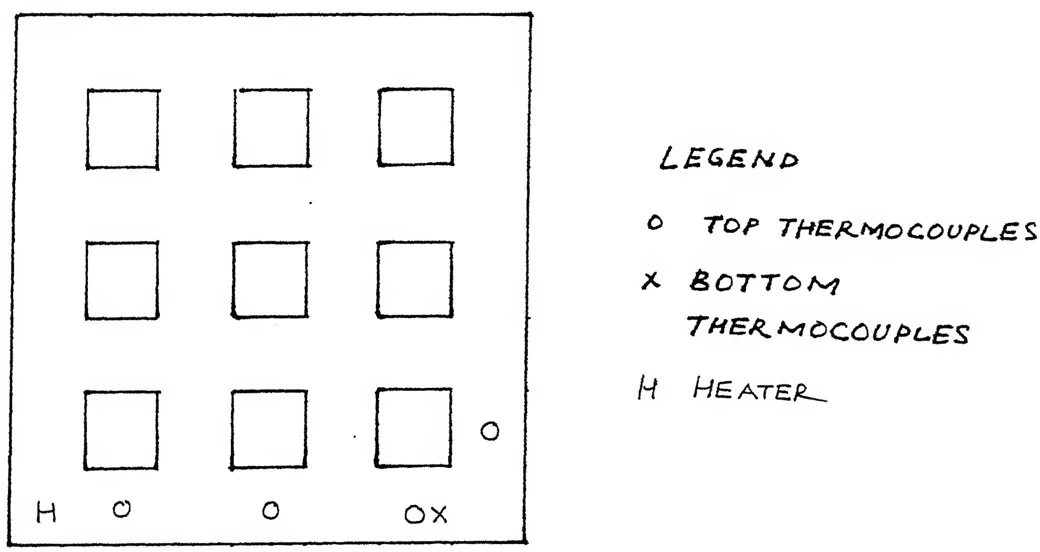
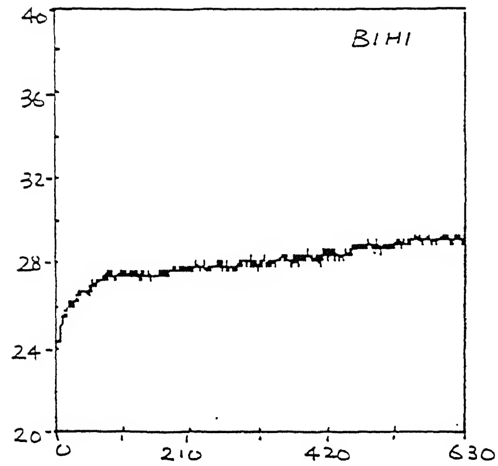
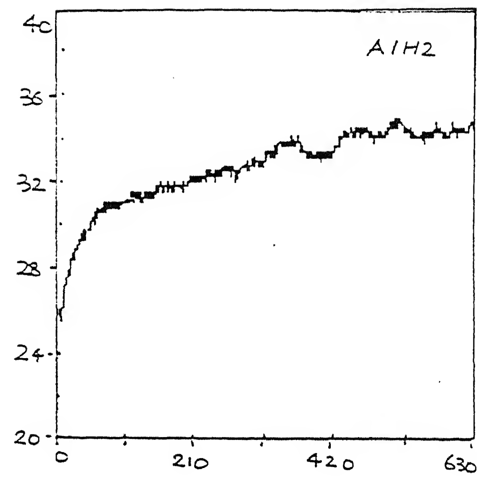


FIG. 3.3(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG 3.3(b)





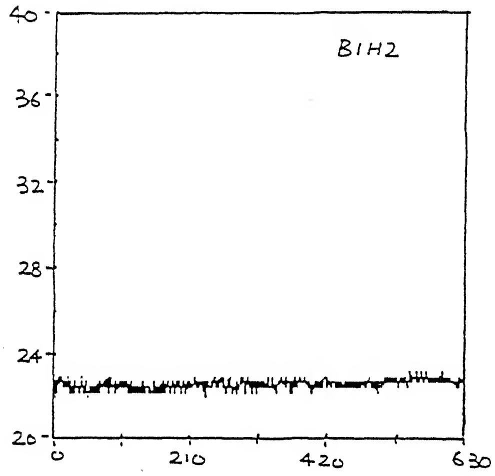
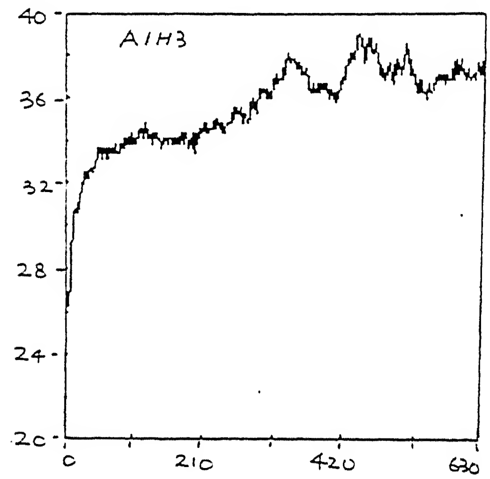
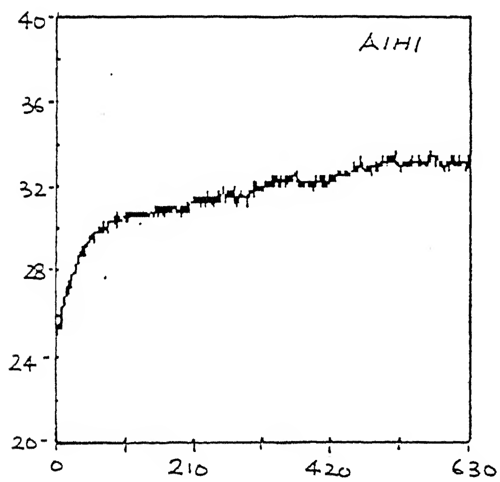


FIG. 3.2(b)





X-AXIS: TIME IN SEC.
Y-AXIS: TEMP. IN °C

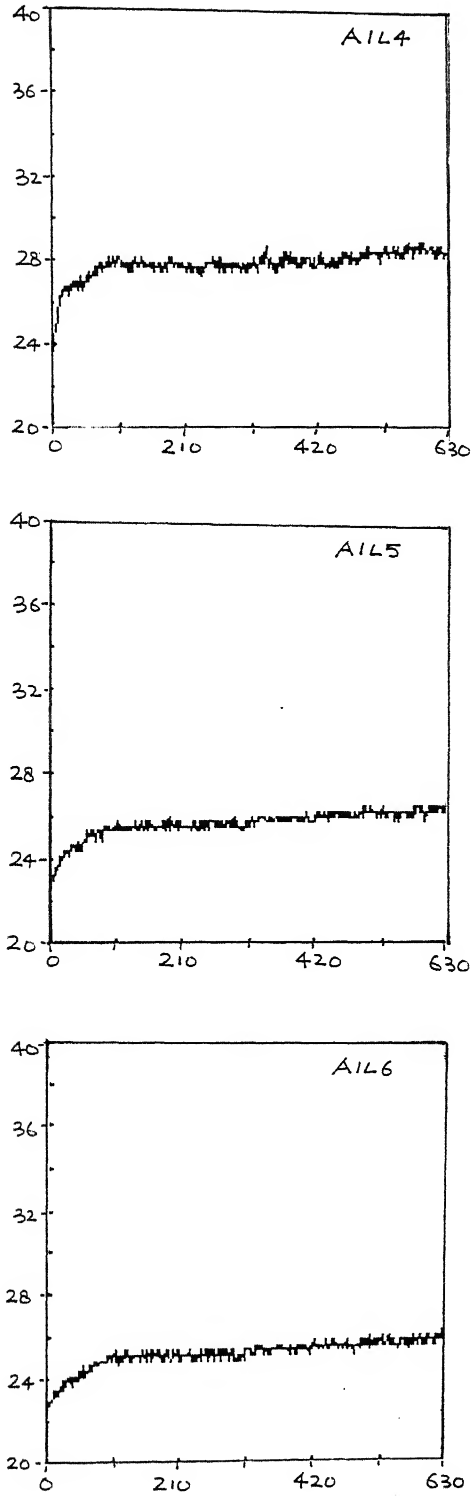
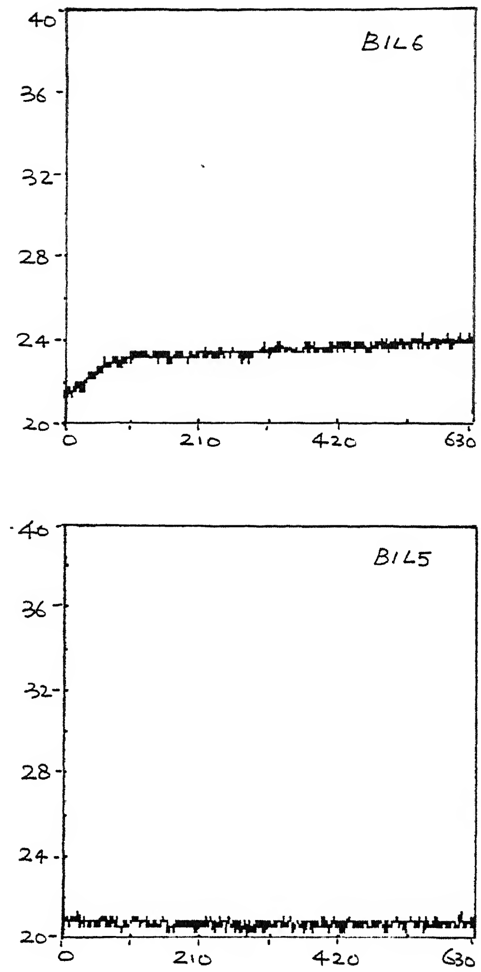


FIG. 3.3(b)



X-AXIS : TIME IN SEC.

Y-AXIS : TEMP. IN °C

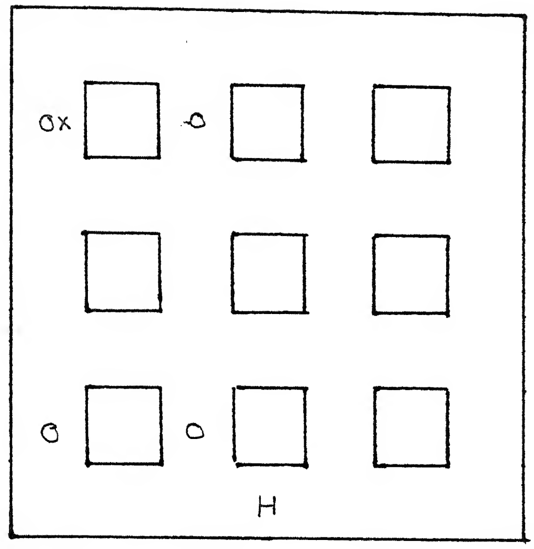
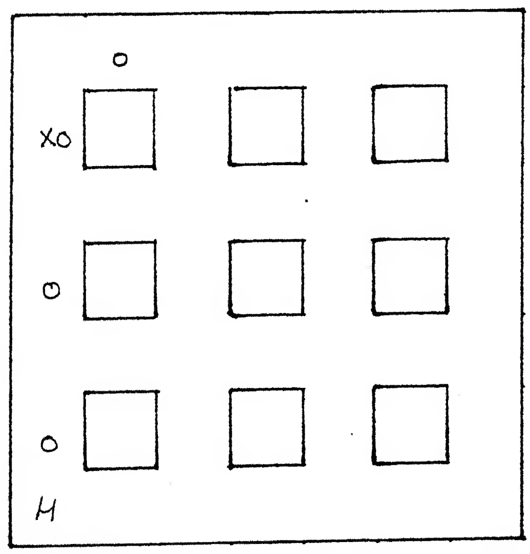


FIG. 3·4(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG 3·4(b)



LEGEND

O TOP THERMOCOUPLES

X BOTTOM THERMOCOUPLES

H HEATER

FIG 3·5(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG 3·5(b)

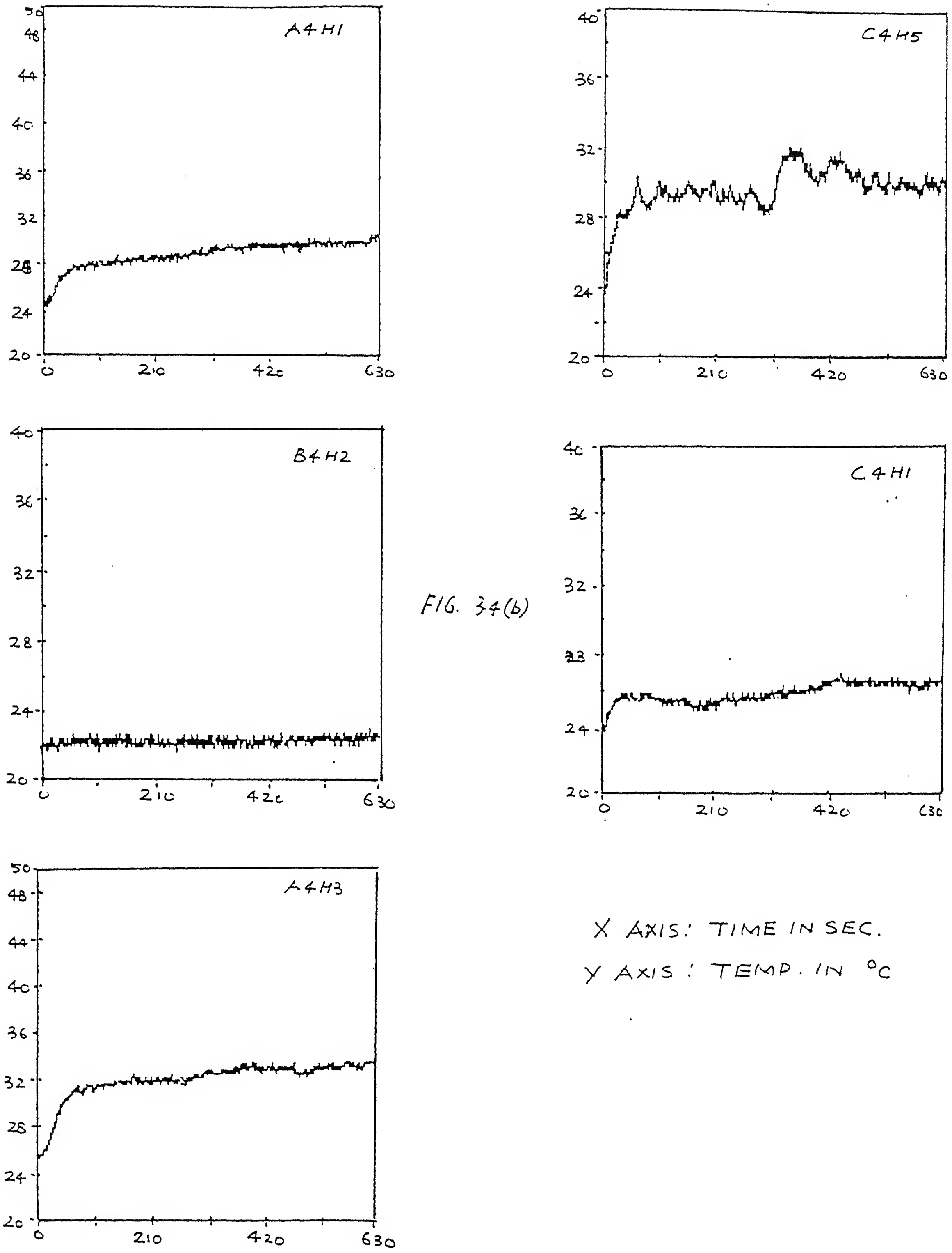


FIG. 34(b)

X AXIS: TIME IN SEC.

Y AXIS: TEMP. IN °C

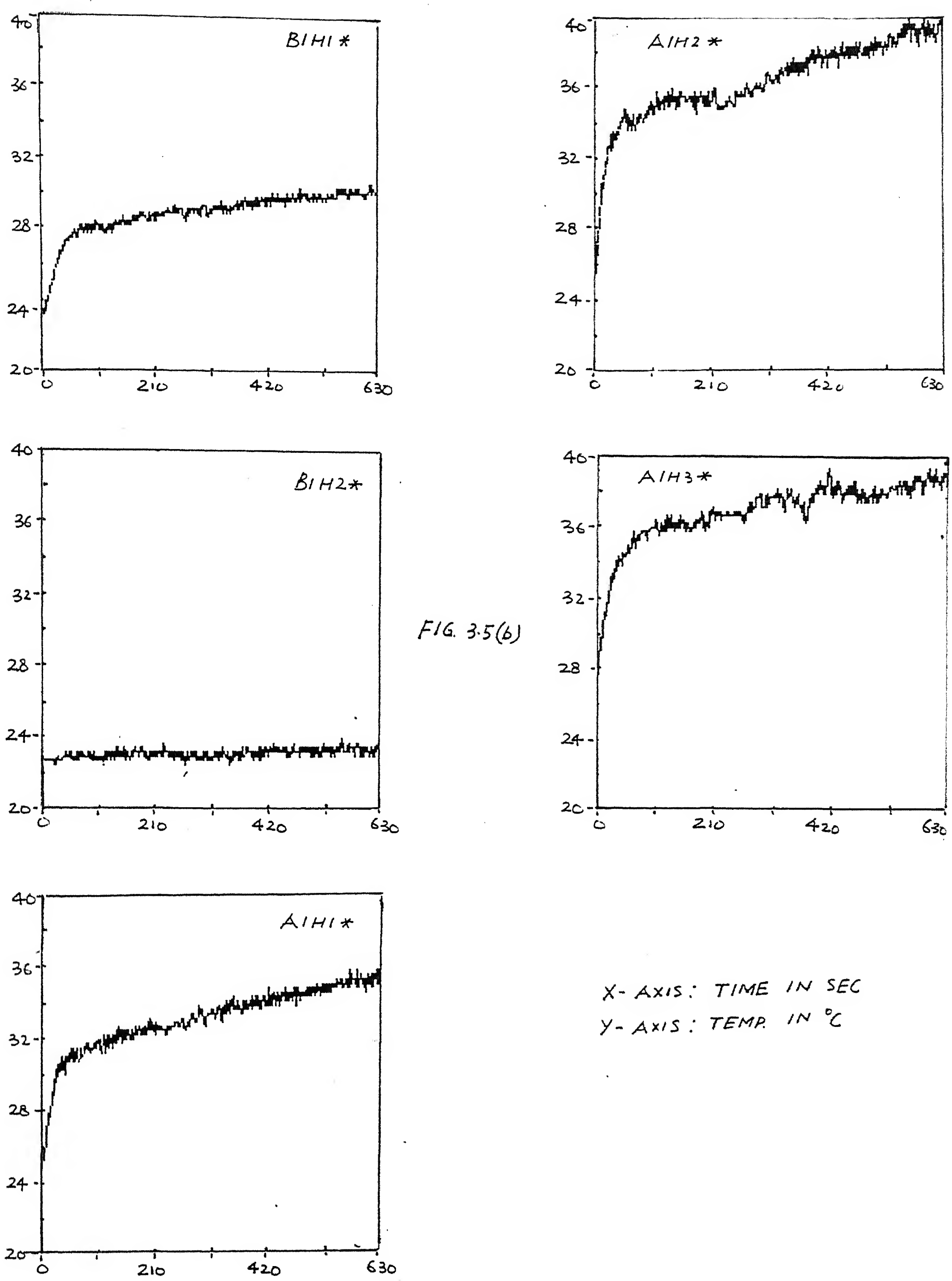


FIG. 3.5(b)

X- AXIS : TIME IN SEC
Y- AXIS : TEMP. IN °C

walls of the enclosure and the plume appears to have a very significant role in the spreading phenomena.

All the temperature patterns exhibit small high frequency fluctuations and for some thermocouples, the temperature versus time curves show low frequency fluctuations of larger amplitude as well. Such high andlow frequencuy fluctuations have been observed by earlier researchers also in similar situations (Quintere, 1978). It is believed that the high frequency fluctuations correspond to small scale turbulent eddies present in the flow while the low frequency fluctuations are due to large scale eddies generated in the flow when it turns around a corner.

The observation that the bottom thermocouples are hardly affected for all combinations of input conditions has led us to analyse the temperature distribution at the top level in more detail. In fact, our flow visualisation studies also reveal that the plume spreads into the entire enclosure adjacent to the roof of the enclosure. Since localized heating is used in the present study, it does not seem to be sufficient to affect the entire quantity of gas within the enclosure. Instead, energy discharged by the heat source into the plume is lost to the environment through the side and top walls which lie adjacent to the plume. For this reason, the subsequent graphs present the effects of various input conditions upon the temperature field at the top level of the enclosure only.

3.5 EFFECT OF INPUT CONDITIONS UPON THE TEMPERATURE DISTRIBUTION ADJACENT TO THE ROOF

An extensive amount of temperature data have been collected for various input conditions during the course of the present experimental investigation, which are available on 24 floppy diskettes. Processing and presentation of all the available data will consume excessive amount of effort and space. Therefore, only representative results covering the whole range of input conditions are presented here. Of the fourteen thermocouples which are placed at the top level, the output of twelve thermocouples are plotted for each set of parameters. For the sake of convenience and clarity, the twelve graphs are presented in two consecutive figures with 6 graphs per figure.

Figs. 3.6(b) and 3.7(b) show the top level temperature distribution for the heater temperature of 200^{o}C, aspect ratio of 0.49 and for the heater placed at location 1. The temperature data recorded by all the thermocouples (except the one which is right above the heater) are qualitatively similar, with a rapid rise initially and slow rise later. The thermocouple situated right above the heater, however, records a nearly instantaneous rise to a high temperature value which is followed by an equally sharp drop (see Fig.3.22). For later period, this thermocouple records a slow increase in temperature. A very important point to be noted here is that the thermocouples situated slightly away from the heat source record higher temperatures some times than the thermocouples

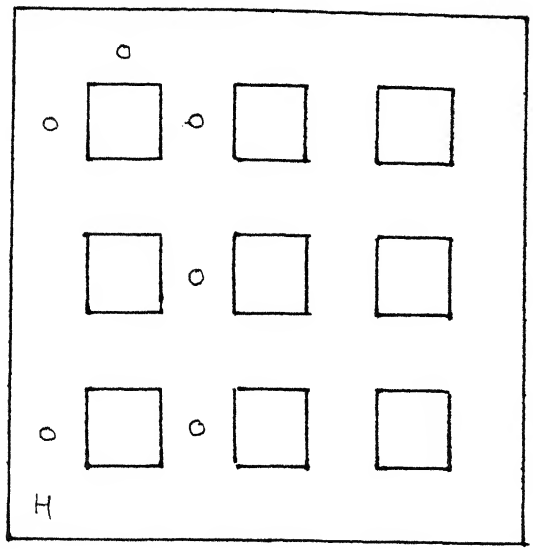


FIG. 3·6(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG 3·6(b)

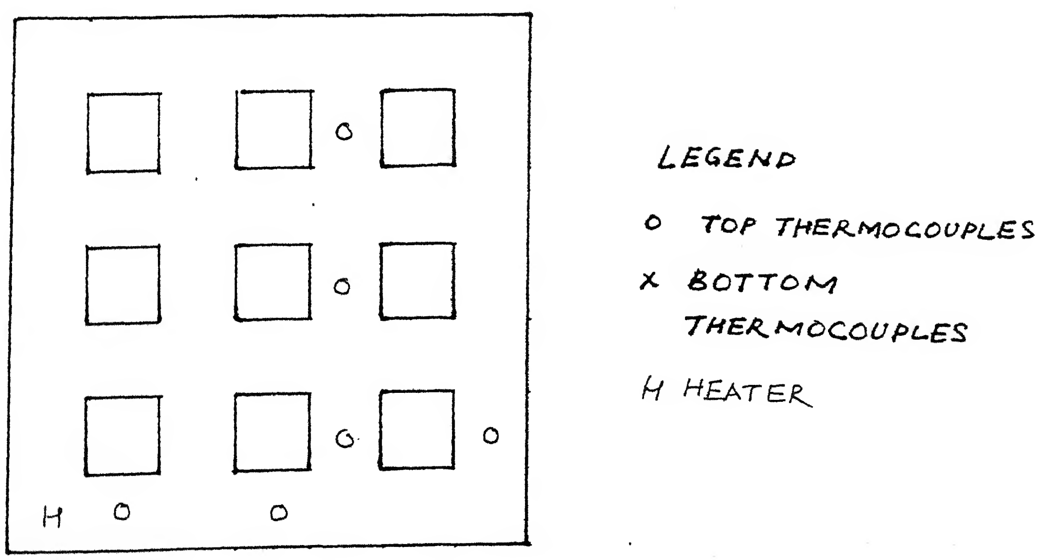


FIG. 3·7(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG 3·7 (b)

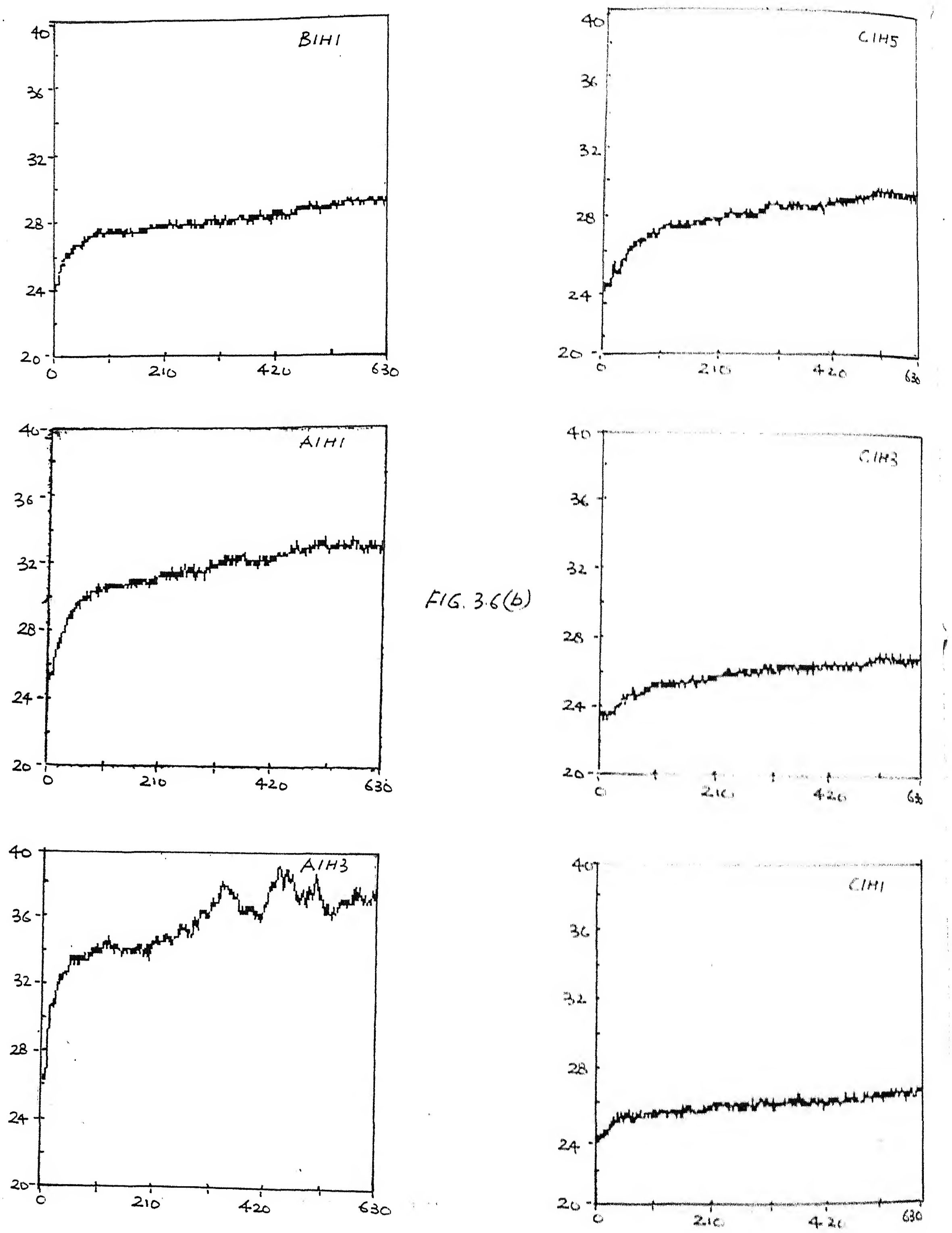
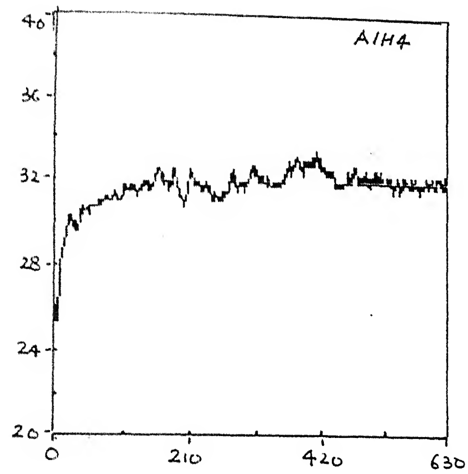
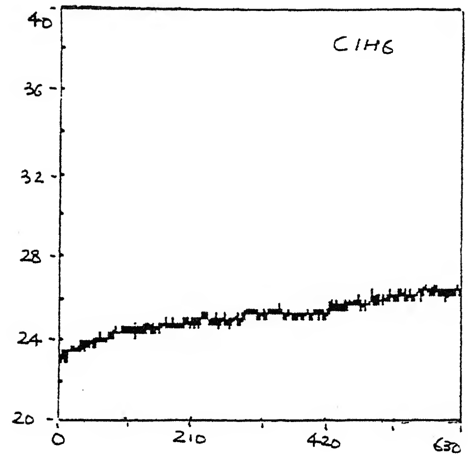


FIG. 3.6(b)

X- AXIS : TIME IN SEC. , Y- AXIS: TEMP. IN °C





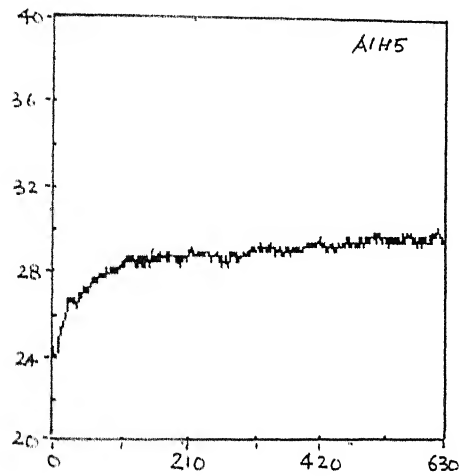
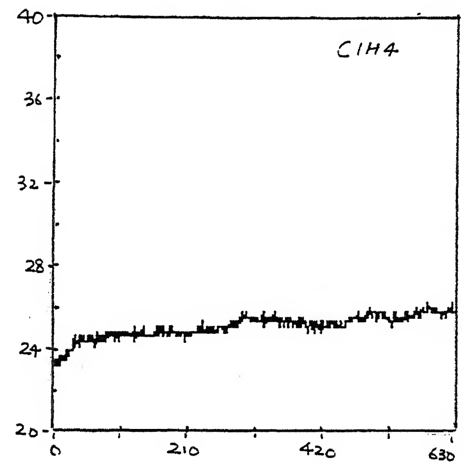
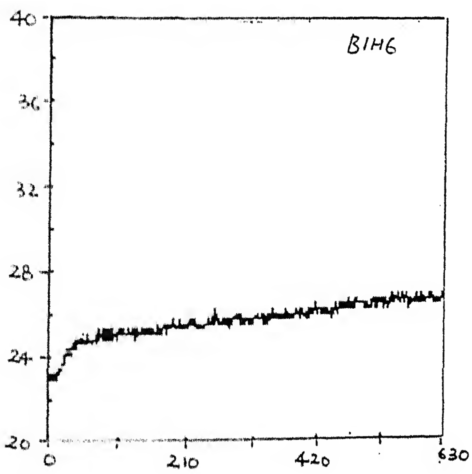
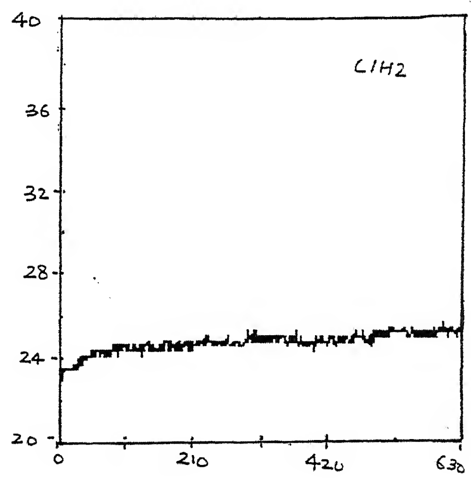


FIG. 3.7(b)







X AXIS: TIME IN SEC.
Y AXIS: TEMP. IN °C

right above the heater. This implies that hot plume is not rising straight above the heater. In fact, it seems to have attached itself to one of the walls very shortly after the start of the experiment. The thermocouple placed right above the heater, therefore, misses the plume completely and does not record a high rise in temperature. For the present configuration of the heater (on one corner of the enclosure), it is believed that the plume flows close to the vertical edge which is common between the front and the left wall of the enclosure and divides itself into two parts. Each of these parts spreads along one of the two corridors with partial entry into the passage between pillars from these corridors. These conclusions are supported by our flow visualisation studies.

Along the two corridors, at whose intersection the heater is placed, the temperature rise progressively decreases with distance away from the heat source. This supports our earlier contention that the plume loses heat energy and momentum along the flow path due to its contact with the wall. The division of the plume between the two corridors does not appear to be symmetric. One of the main reason that can be attributed for this asymmetry is that the heat source is rectangular in shape. The larger stream of the plume appears to be along the width of the plate. However, it is not clear at this moment whether the asymmetry arises due to the manner in which the plume attaches itself with the wall.

With regard to the thermocouples in the interior portion of the enclosure, they also exhibit a progressive decrease in temperature along the respective corridor with distance from

the heat source. The large amplitude low frequency fluctuations in temperature are observed only for those thermocouples which are closest to the corner, supporting the conclusion drawn earlier that corners tend to generate large scale eddies. These eddies appear to lose strength as the plume flows further along the length of the respective corridor. It is clear from the graphs that within the duration of 630 seconds, even thermocouples located far away from the heat source record rise in temperature and most of the thermocouples show the attainment of a near steady state situation.

Figs.3.8(b) and 3.9(b) show the temperature distribution at the top level for the second position. The heater temperature is 200^{o}C and the aspect ratio is 0.49. Most of the observed features in these two graphs, resemble those of Figs. 3.6(b) and 3.7(b). The main differences between the two sets of results are listed below:

(i) The data recorded by the thermocouple A4 which is placed right above the heater shows the highest rise in temperature among all the thermocouples. This indicates that the plume rises vertically straight in this case, perhaps due to the fact that it rises between 2 vertical surfaces, one corresponding to the enclosure wall and the other corresponding to the adjacent pillar (See Fig. 3.22).

(ii) Apart from the thermocouple right above the source, the largest increases in temperature are recorded by the thermocouples A3,A5 and C5. This implies that the plume divides into 3 major parts along the corridors which

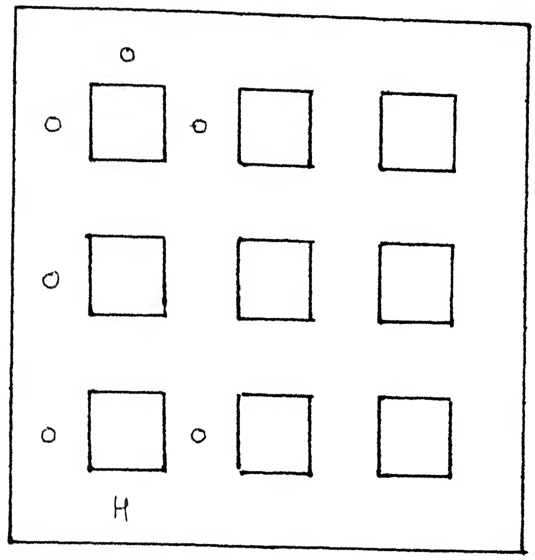
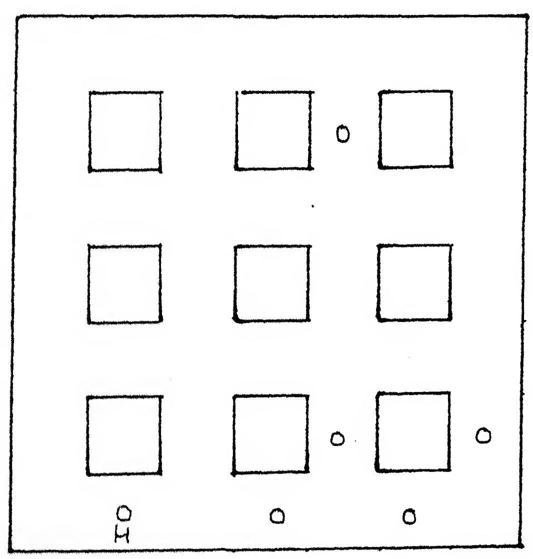


FIG. 3.8(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG. 3.8(b)



LEGEND

o TOP THERMOCOUPLES

x BOTTOM THERMOCOUPLES

H HEATER

FIG. 3.9(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG 3.9(b)

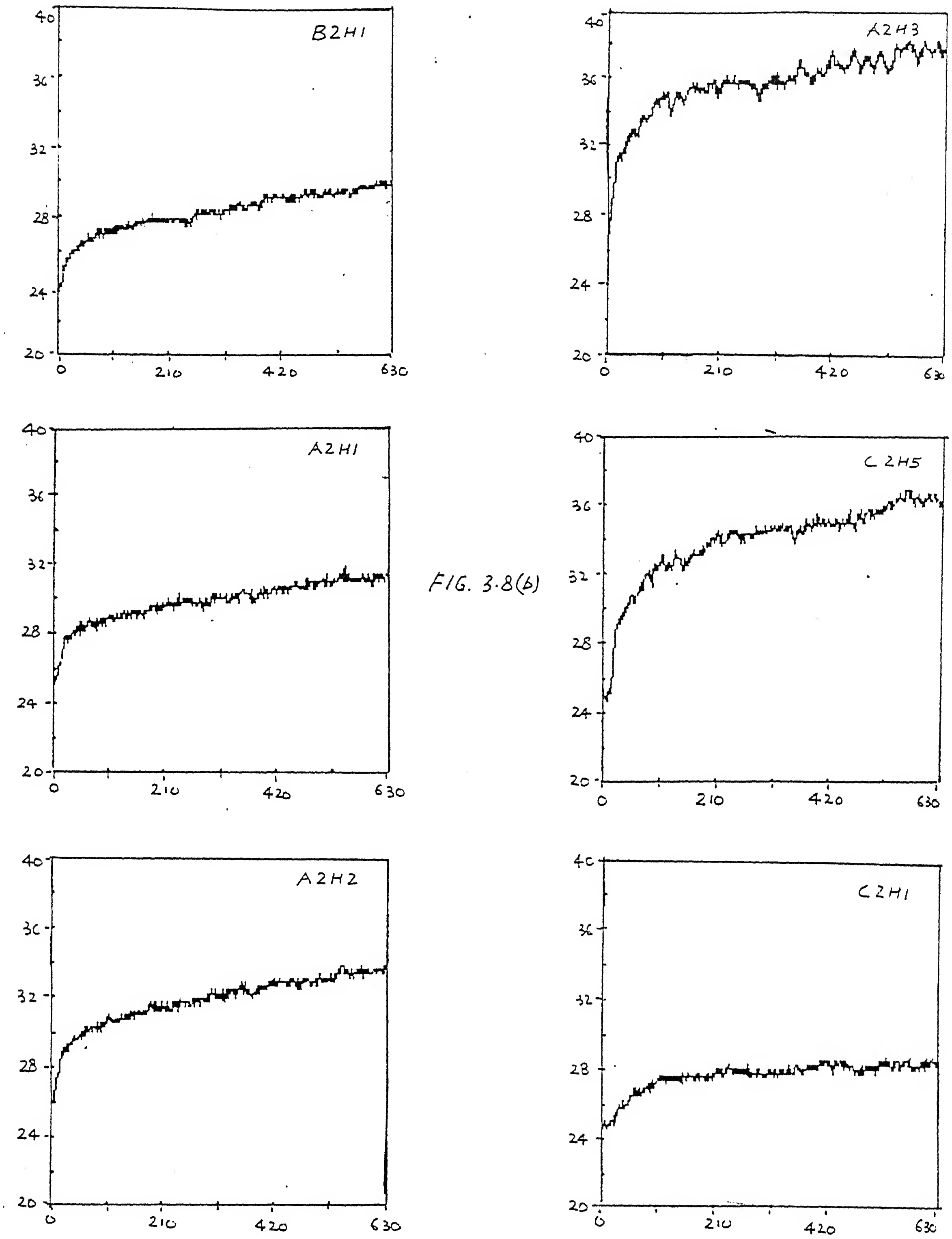
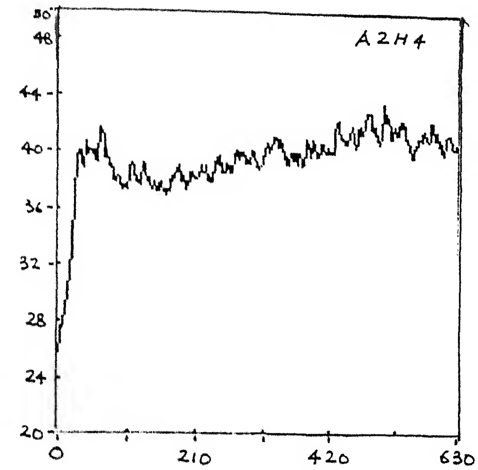
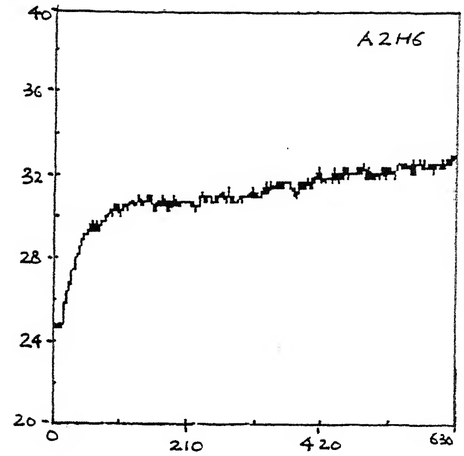


FIG. 3.8(b)

X- AXIS : TIME IN SEC. , Y- AXIS : TEMP. IN °C





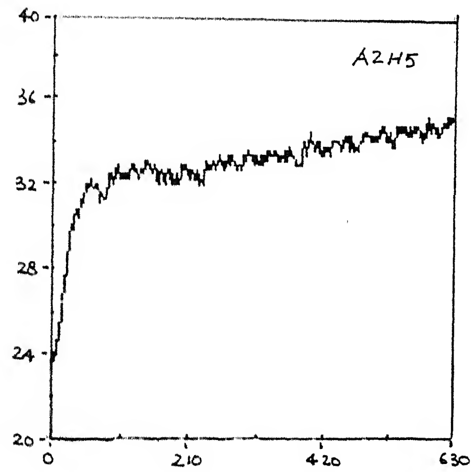
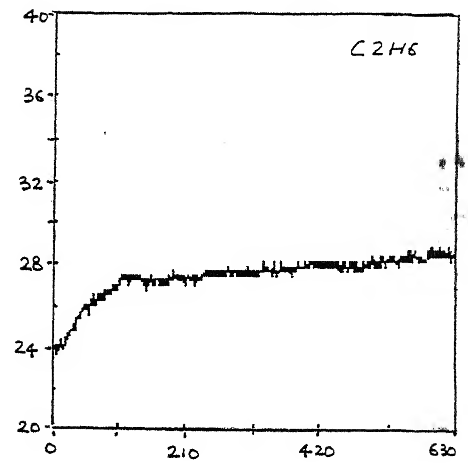
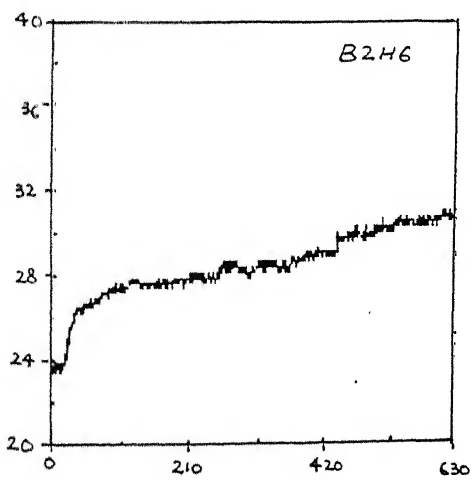
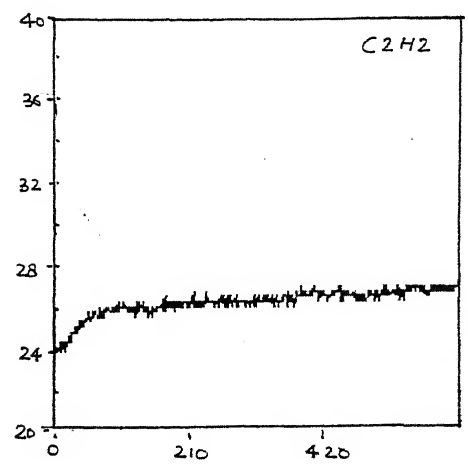


FIG. 3.9(b)







X-AXIS: TIME IN SEC., Y-AXIS: TEMP. IN °C

contain the three thermocouples mentioned above. The same conclusion is arrived at from the corresponding flow visualisation study.

The low frequency fluctuations are again observed primarily for the three thermocouples situated close to the corner between the locations of the thermocouples A3 and A4.

Figs. 3.10(b) and 3.11(b) show the results corresponding to the third heater position with other parameters remaining unchanged as in Figs.3.8(b) and 3.9(b). Judging from the largest temperature readings recorded, it may be concluded that the plume divides into three main parts in this situation also. One component of the plume seems to go through the passage which contains the thermocouple C5. The other two branches of the plume, flow along the corridor which is adjacent to the front wall. Of course, one of these two branches flows in the direction of thermocouple A4 and the other in the direction of thermocouple A5.

Compared to the previous heater position, the temperature levels recorded are in general lower for all the thermocouples. This indicates that the plume has again attached itself to the front wall and flows along the top edge of the surface. This conclusion is supported by the low temperature recording of thermocouple right above the heat source. Now we shall make a comparison between Fig. 3.6 and Fig. 3.7 and the present figures. In general, the temperature rises are more or less of the same order because both cases correspond to the case of the plume attached to the wall. However, when the heater is placed at the third position, the

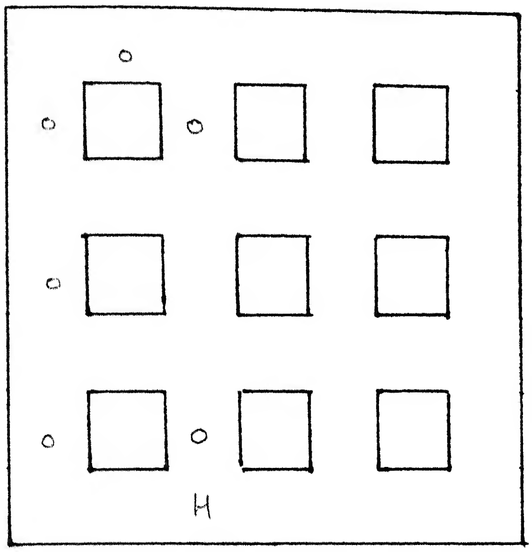
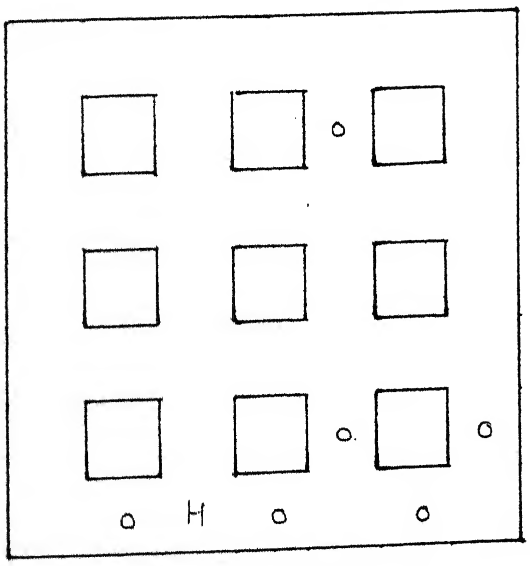


FIG.3.10(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG.3.10(b)



LEGEND

o TOP THERMOCOUPLES

x BOTTOM THERMOCOUPLES

H HEATER

FIG.3.11(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG. 3.11(b)

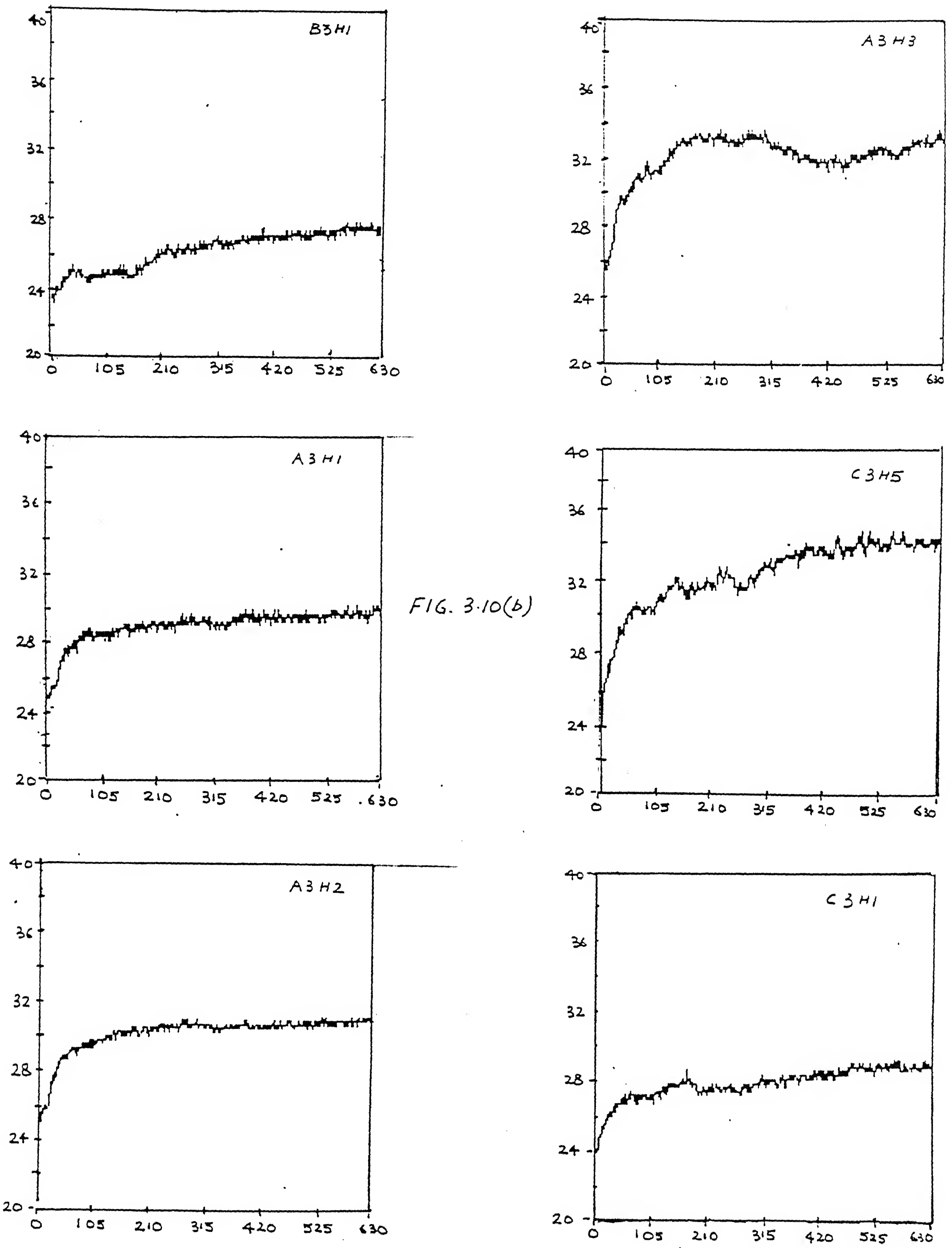


FIG. 3·10(b)

X - AXIS : TIME IN SEC. , Y- AXIS : TEMP IN °C

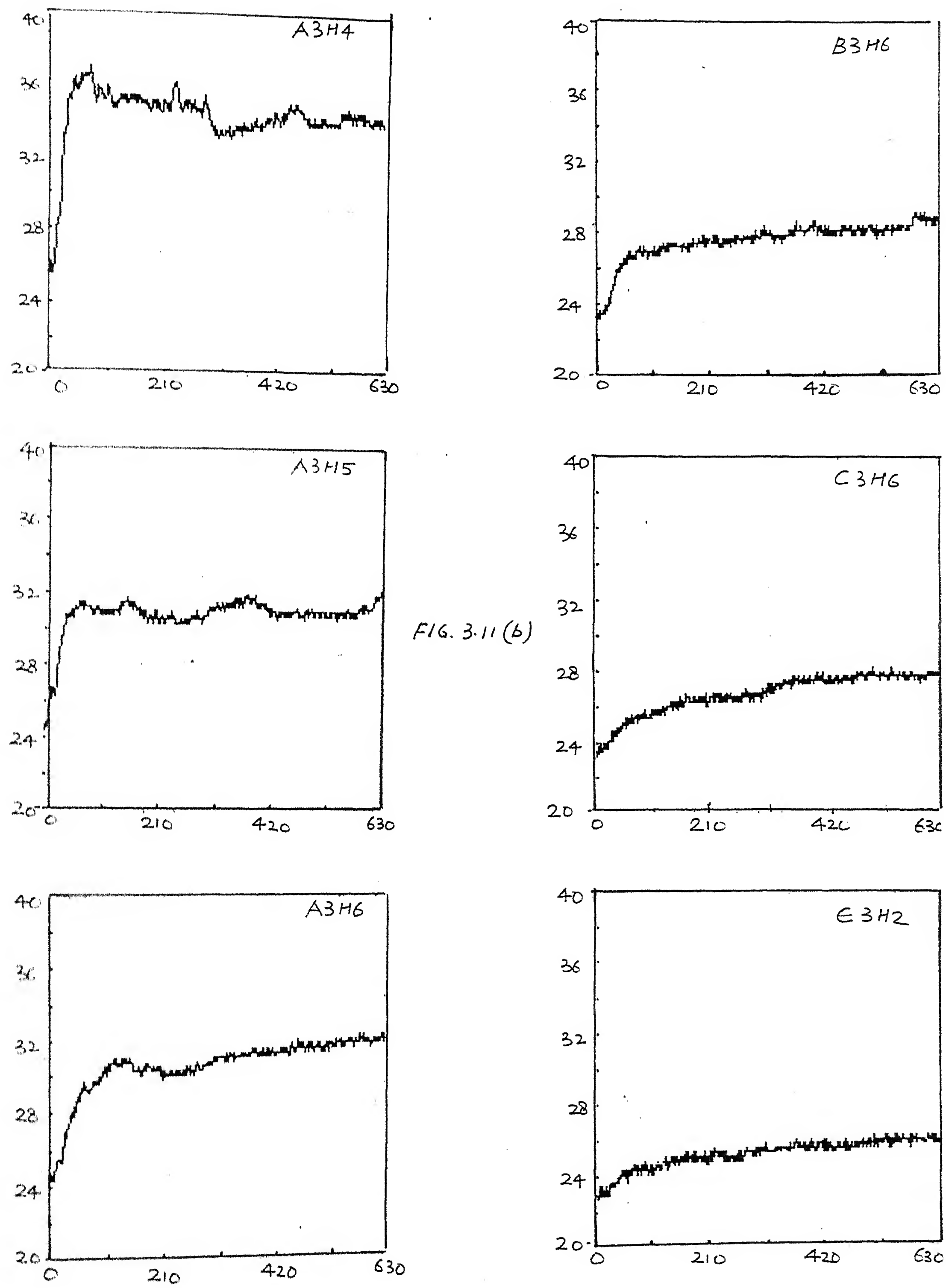


FIG. 3.11 (b)

X-AXIS : TIME IN SEC. , Y-AXIS : TEMP. IN °C

temperature values recorded at the central positions of the heater are higher than those obtained with the heater placed at position 1. By the same token, the probes in the rear corridor of the enclosure (which contains the thermocouple B1), in general, register higher temperature increase when the heater is at location 1. Apart from these differences, the trends seen for both the situations conform to the earlier observations that temperature decreases with horizontal distance measured from the heat source.

The graphs shown in Figs. 3.12(b) and 3.13(b) correspond to the fourth position of the heater with the other parameters remaining the same as for the graphs discussed above. In general, the temperature rise recorded by most of the thermocouples is higher than those measured for heater positions 1 and 3. This confirms the hypothesis that the plume gets attached to the wall when it faces wall on only one side. When the plume is straddled by the pillar and the wall, it rises straight above the heater, without attaching itself to either solid surface (See Fig. 3.22).

The distribuition of temperatures indicates that the plume divides into four parts and flows into the corridors which contain thermocouples A4, A6, C5 and C6. The strengths of the flow in the main channel containing A4 and A6 seem to be greater than those through the other two channels. Another interesting feature shown by the results is that the low frequency fluctuations are recorded by all the four thermocouples mentioned above. As described earlier, these seem to be due to the eddies generated when the flow turns around a corner or an edge.

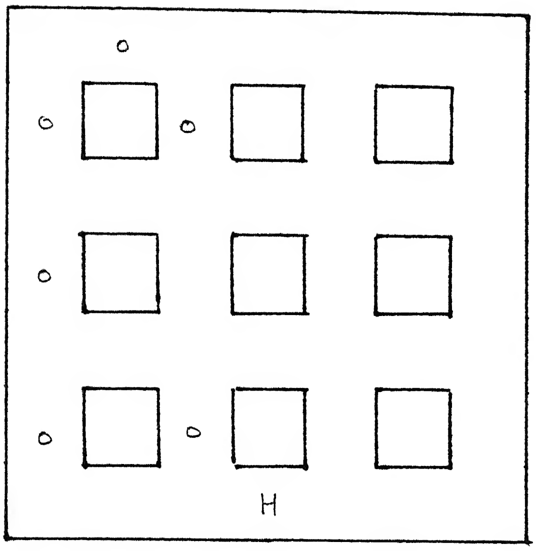


FIG. 3.12(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG. 3.12(b)

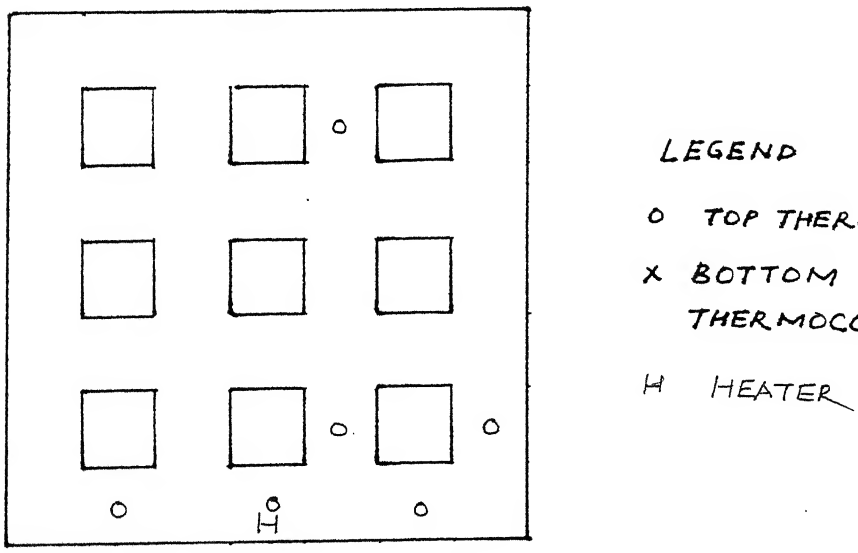


FIG. 3.13(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG. 3.13(b)

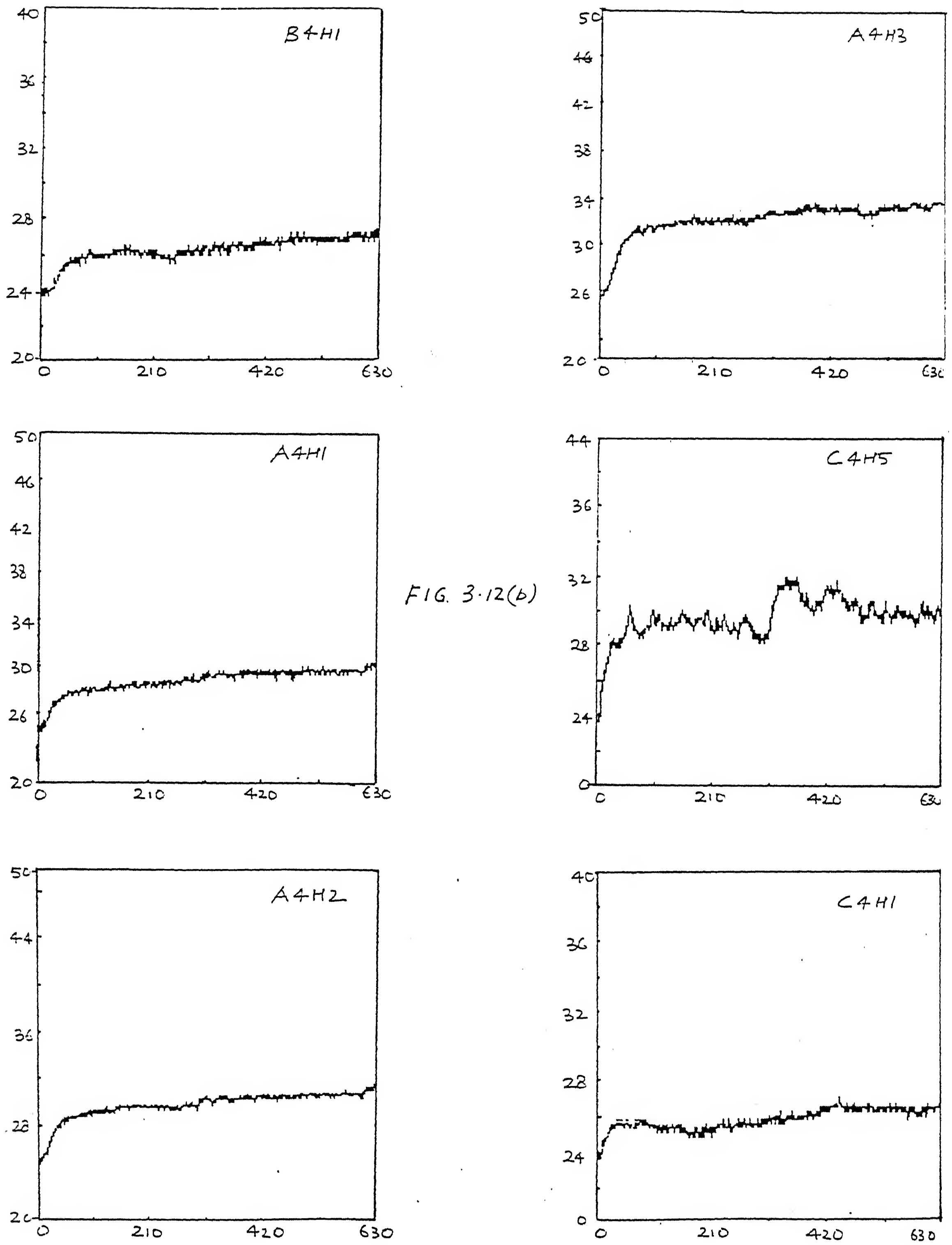
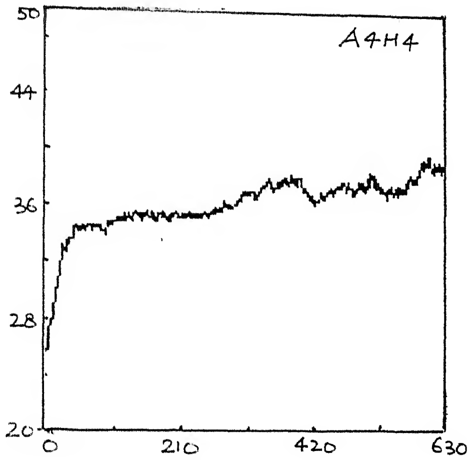
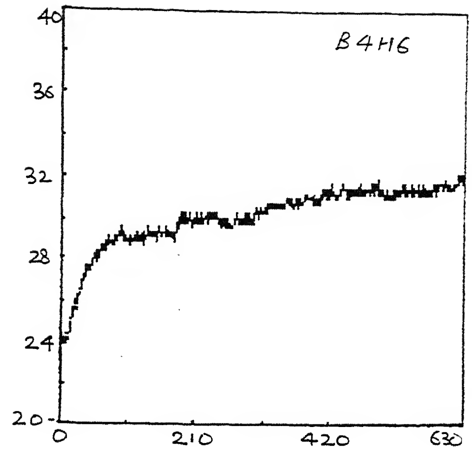


FIG. 3·12(b)

X-AXIS: TIME IN SEC, Y-AXIS: TEMP IN °C





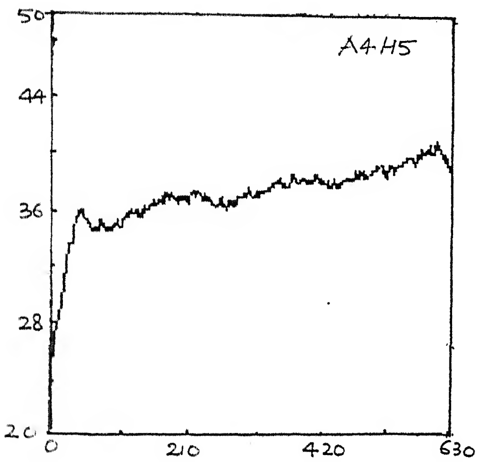
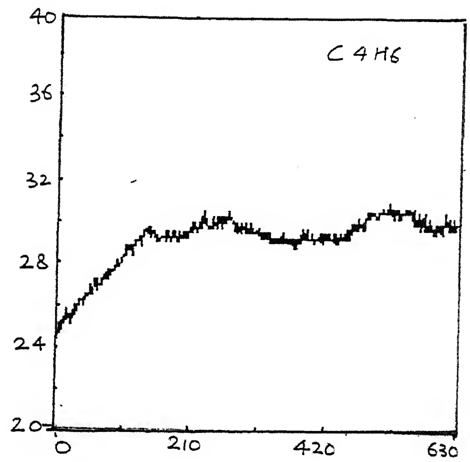
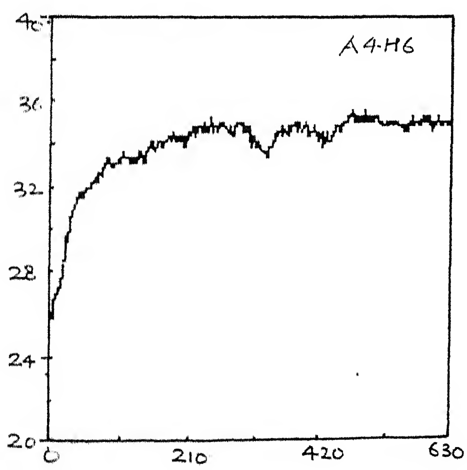
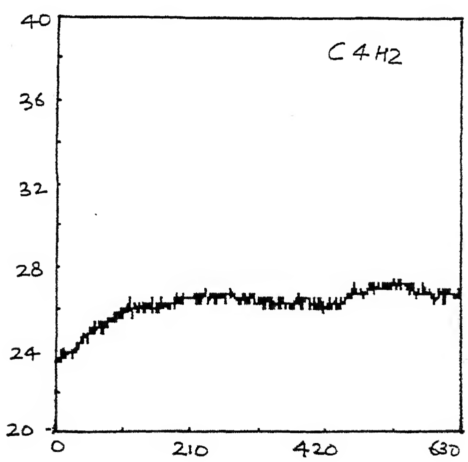


FIG. 3.13(b)







X- AXIS: TIME IN SEC. , Y-AXIS: TEMP IN °C

Figs. 3.14(b) and 3.15(b) show the transient temperature variations corresponding to the lowest heating level and the first heater location, for the aspect ratio of 0.49. The flow patterns for this case seem to be quite similar to those observed for the highest heating level in Figures 3.6 and 3.7. The highest temperatures are recorded by, the two thermocouples A3 and A4., indicating that the flow divides into two main parts along the corridors containing these thermocouples. The temperature levels recorded for this situation are however, smaller than those in Figures 3.6 and 3.7. This is as expected since the plate with a lower temperature will discharge less heat energy into the plume. The temperature rise of the gas appears to increase nonlinearly with the plate temperature. This, we believe, is a consequence of the increase in the natural convection heat transfer coefficient with the plate temperature. It is also observed that the low frequency fluctuations are less noticeable for the present case as compared to those of the highest plate temperature situation. This may be due to the decrease in plume velocity, with the decrease in the heat source temperature.

Figs. 3.16(b) and 3.17(b) show the results for the lowest heater temperature for the heater location of 4 and the aspect ratio of 0.49. As observed for the highest heater temperature condition, the temperature values within the enclosure are generally larger when the heater is placed at the fourth location than when it is placed at the first location. This effect is very clearly seen by comparing the results of Figs.3.14(b) and 3.15(b) with those of the present figures.

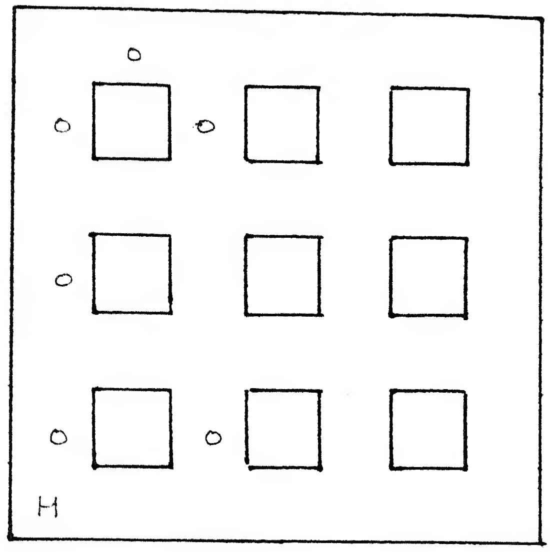


FIG. 3.14(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG. 3.14(b)

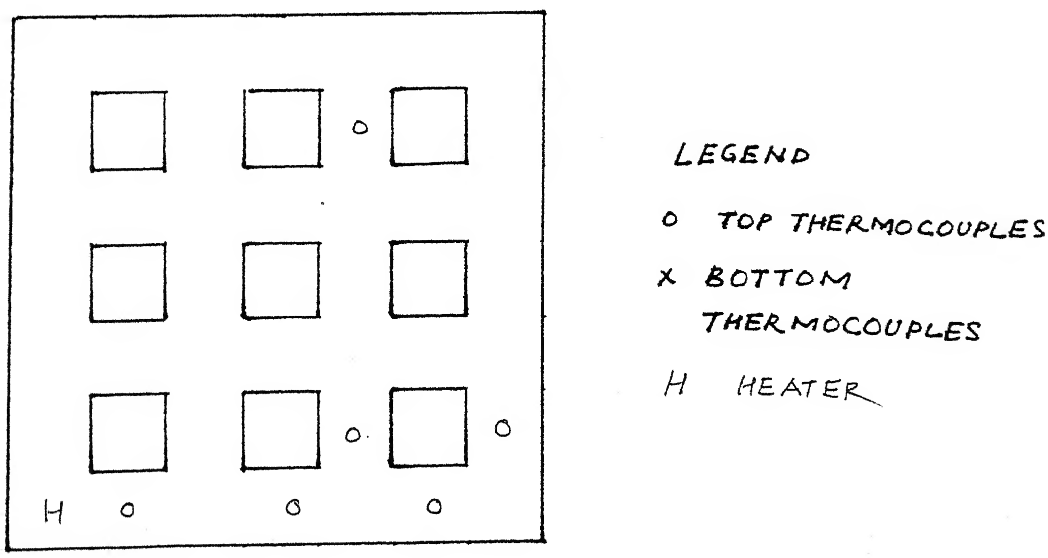


FIG. 3.15(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG. 3.15(b)

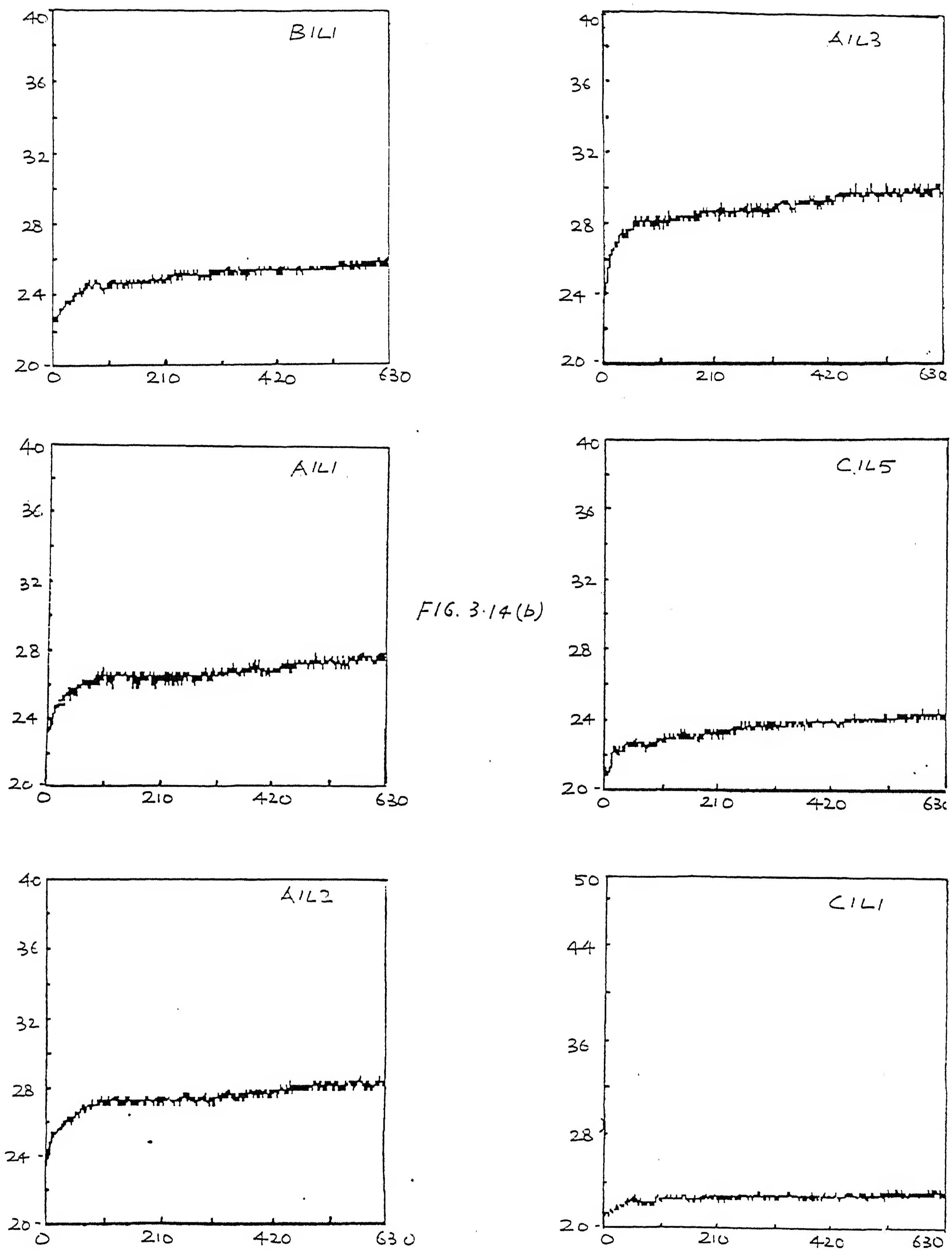


FIG. 3.14(b)

X-AXIS: TIME IN SEC., Y-AXIS: TEMP IN °C

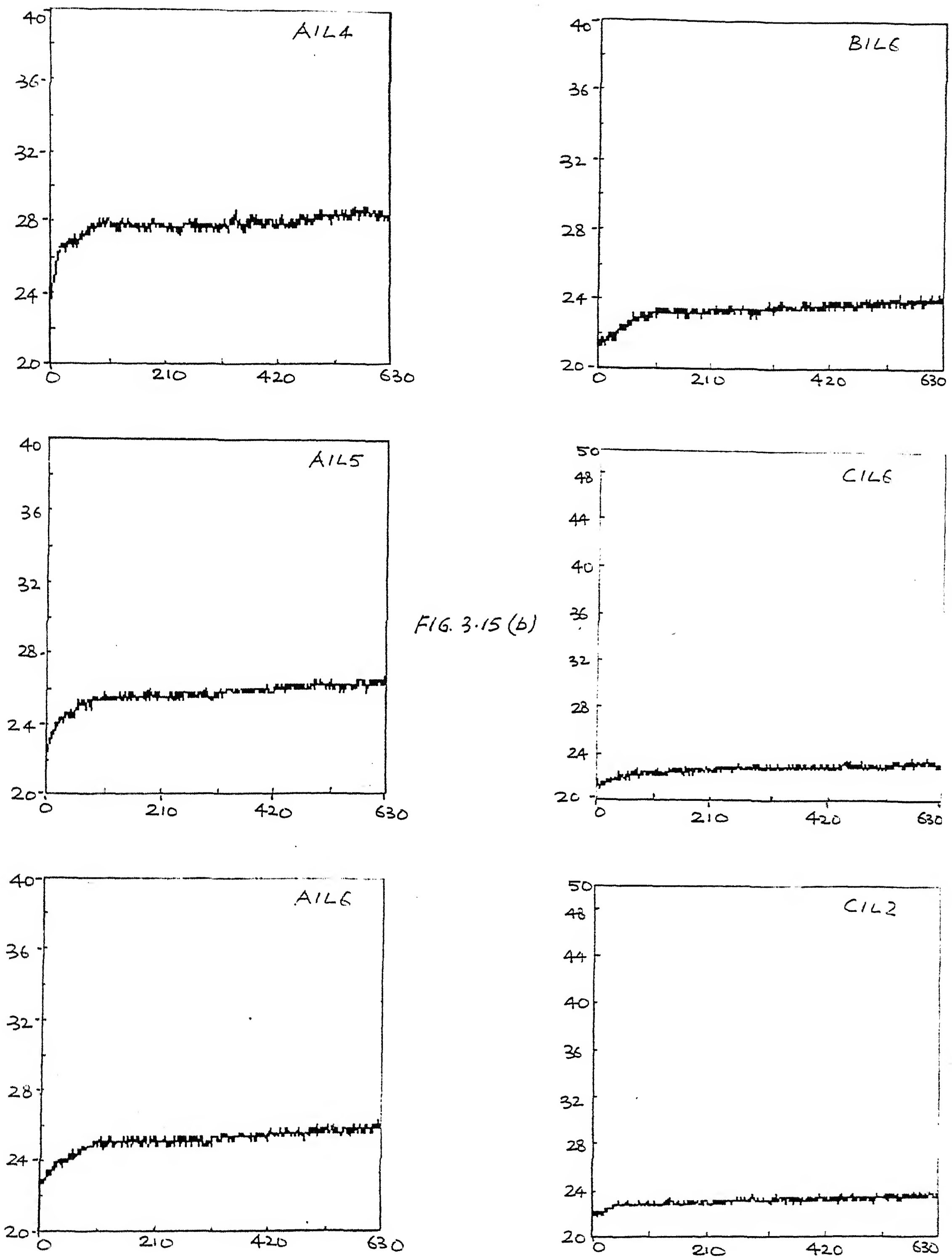


FIG. 3.15 (b)

X - AXIS : TIME IN SEC , Y - AXIS : TEMP IN °C

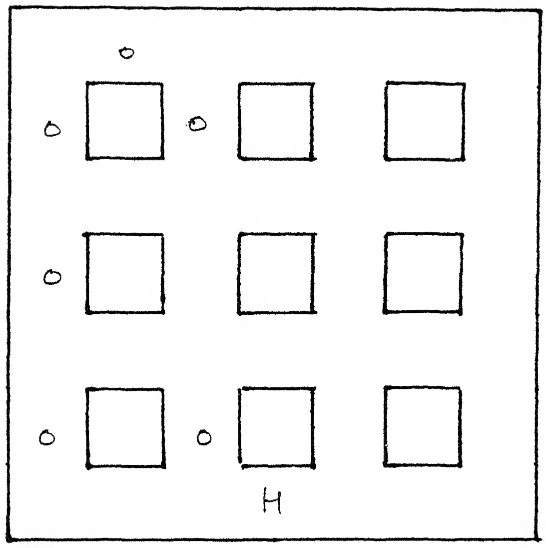
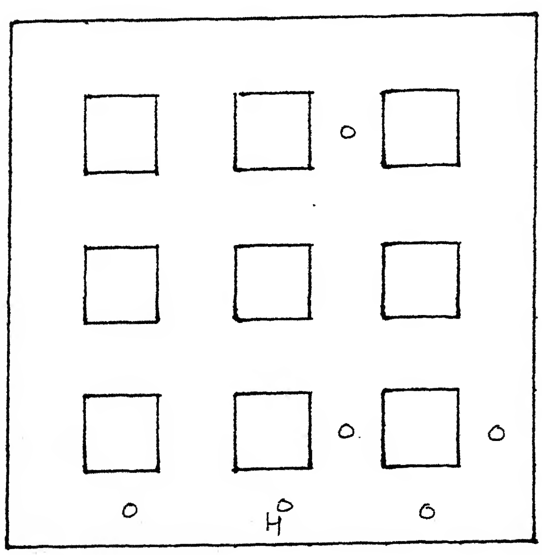


FIG. 3.16(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG. 3.16(b)



LEGEND

o TOP THERMOCOUPLES

x BOTTOM THERMOCOUPLES

H HEATER

FIG. 3.17(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG. 3.17(b)

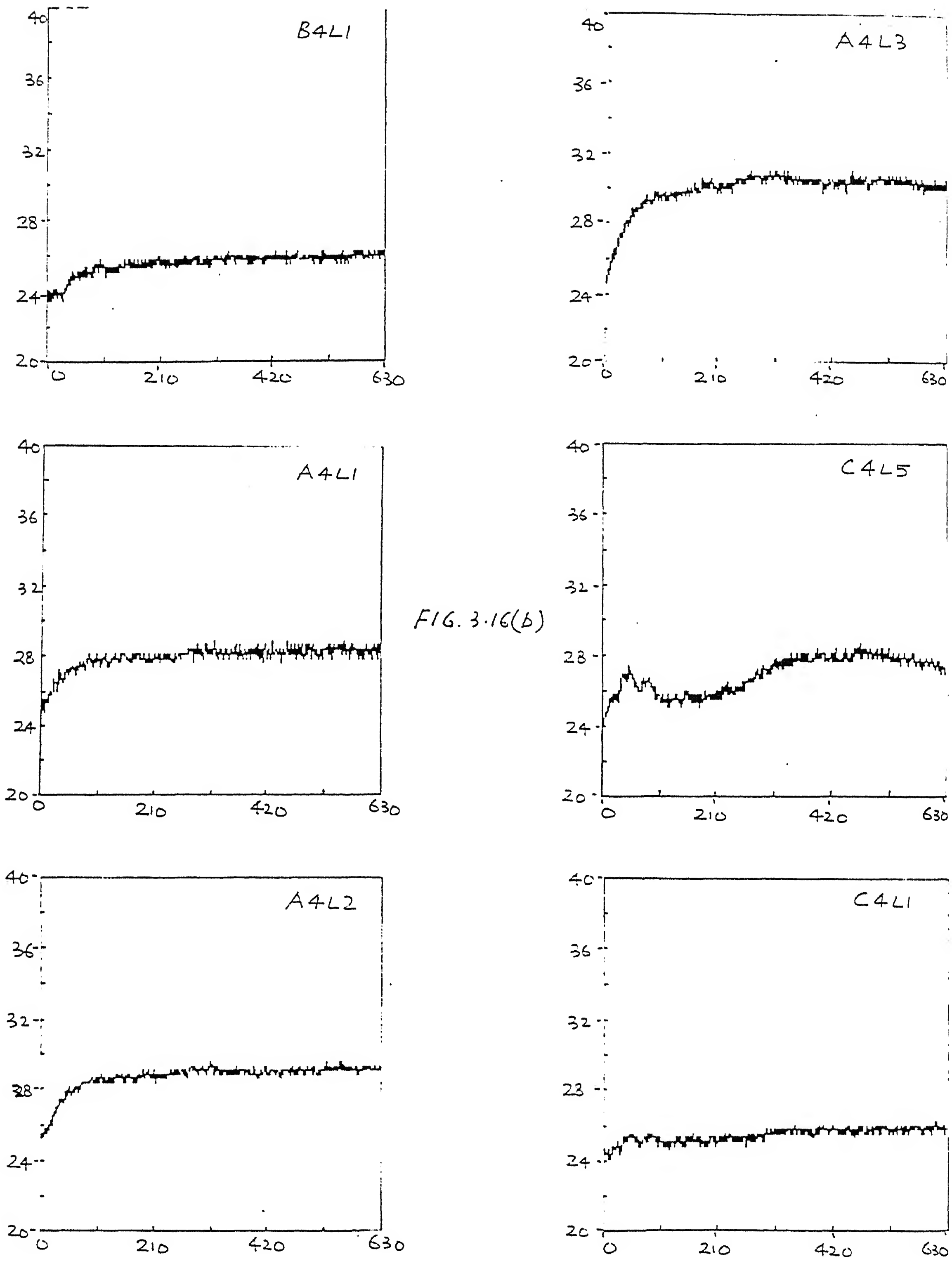


FIG. 3.16(b)

X-AXIS : TIME IN SEC , Y- AXIS: TEMP. IN °C

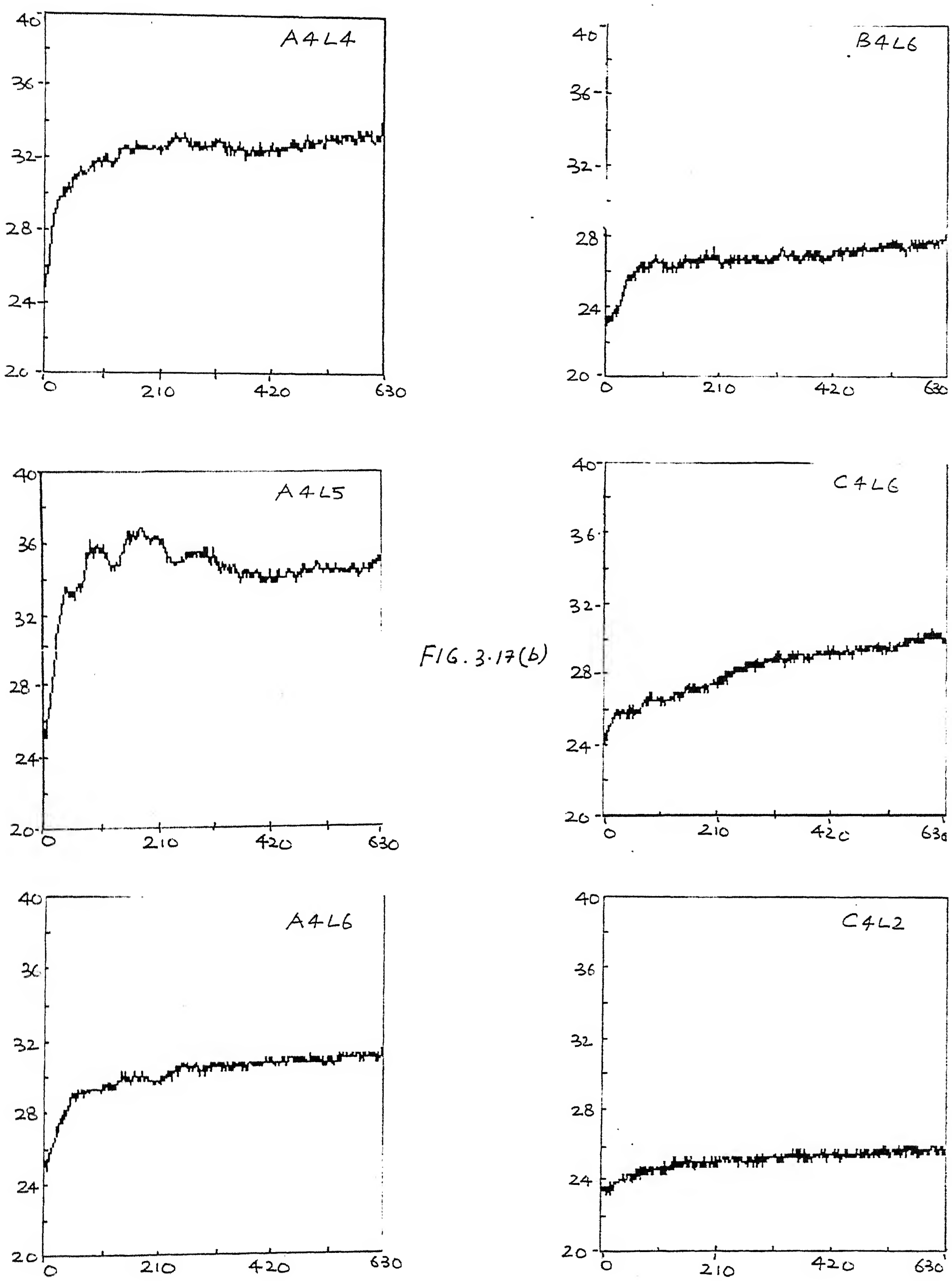


FIG. 3.17(b)

X-AXIS: TIME IN SEC. , Y-AXIS: TEMP. IN °C

It is therefore, evident that plume rises straight above the heater for the situation under consideration while it attaches itself to the wall corresponding to the first heater position. The flow appears to divide into four branches along the corridors containing the thermocouples A4, A5,, C5 and C6. All these features are similar to those observed for the highest heating level situation.

3.6 EFFECT OF THE ENCLOSURE ASPECT RATIO UPON THE TEMPERATURE DISTRIBUTION

The temperature data recorded by a few representative thermocouples at the top level of the enclosure are compared for the two aspect ratios in Figs. 3.18(b) through 3.21(b). The first two of these figures correspond to the first heater position and the last two correspond to the fourth heater position . From the Figs. 3.18(b) and 3.19(b), it is observed that the temperature readings are higher for the smaller aspect ratio. It is worthy to note that these graphs correspond to the situation when the plume attaches itself to the wall. For the smaller enclosure, the height of attachment is less, leading to less heat loss from the plume. Due to this, more energy remains with the plume which is seen in the form of higher temperature values recorded. In Figs.3.20(b) and 3.21(b) also, it is observed that the temperature values are higher for the enclosure with smaller aspect ratio. Although the plume does not attach itself to any of the walls in this case (heater location 4), the heat transfer between the plume and the walls seem to be reduced considerably when the height of the enclosure is reduced. Fig. 3.22 shows the

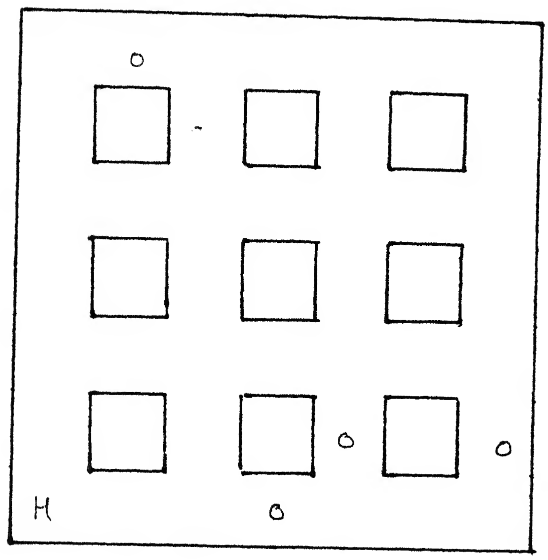
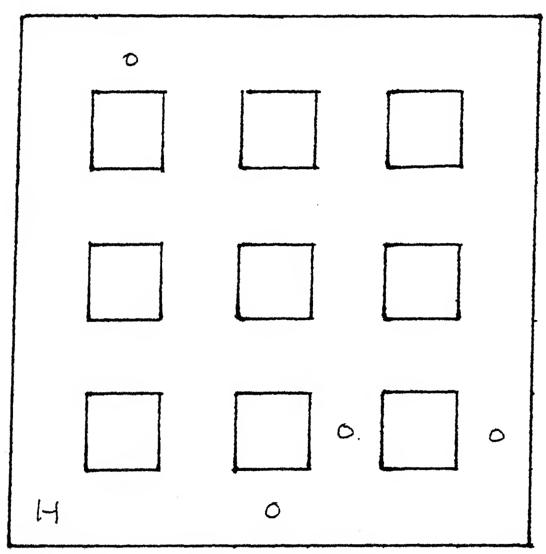


FIG. 3·18(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG. 3·18(b)



LEGEND

o TOP THERMOCOUPLES

x BOTTOM THERMOCOUPLES

H HEATER

FIG. 3·19(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG. 3·19(b)

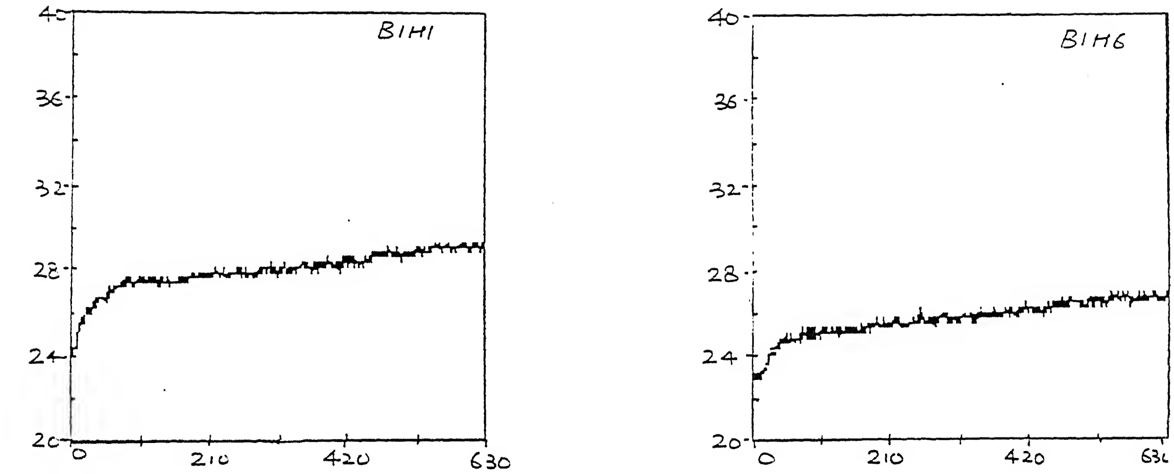
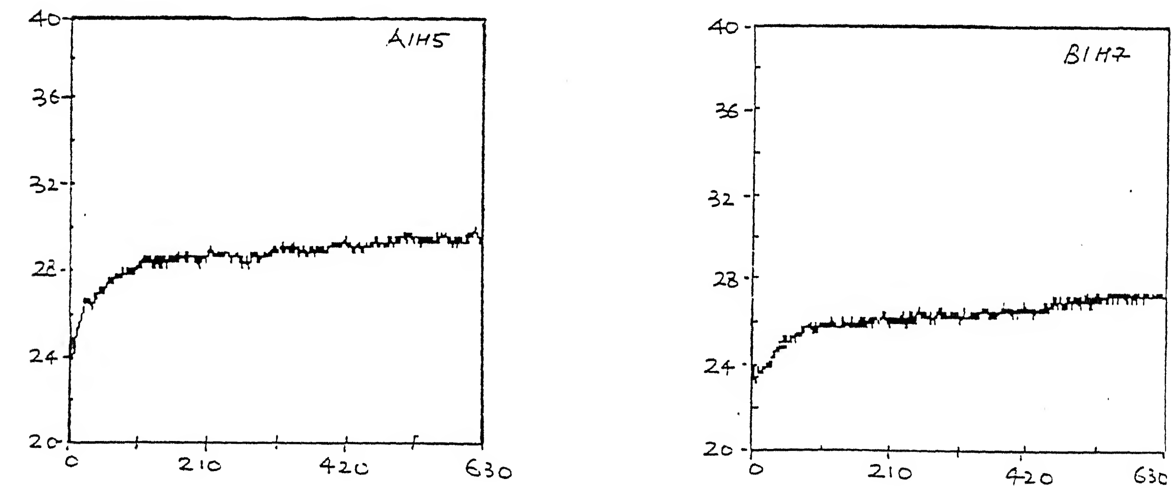


FIG. 3.18(b)



X - AXIS : TIME IN SEC.

Y- AXIS : TEMP. IN °C

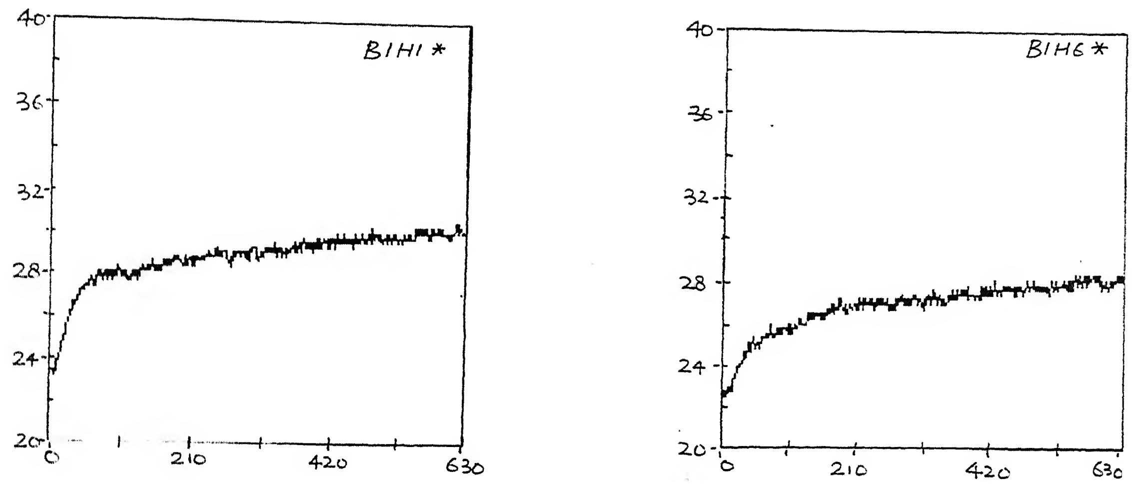
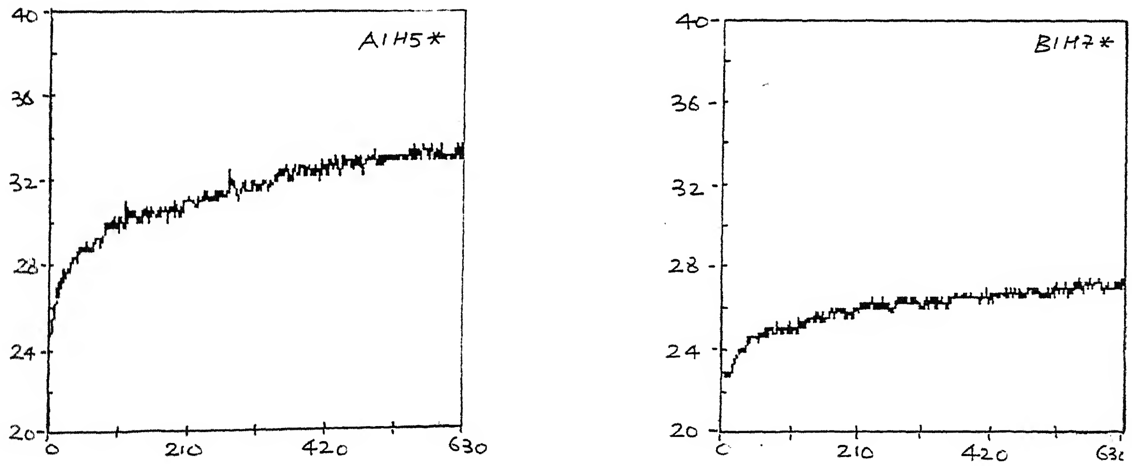


FIG. 3.19 (b)



X- AXIS: TIME IN SEC
Y- AXIS: TEMP. IN °C

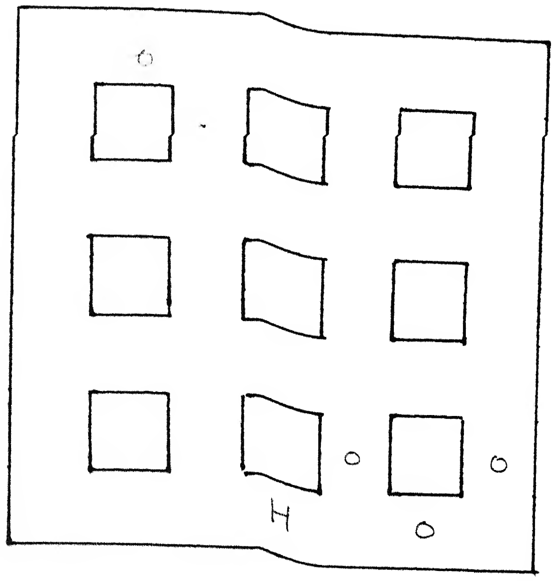
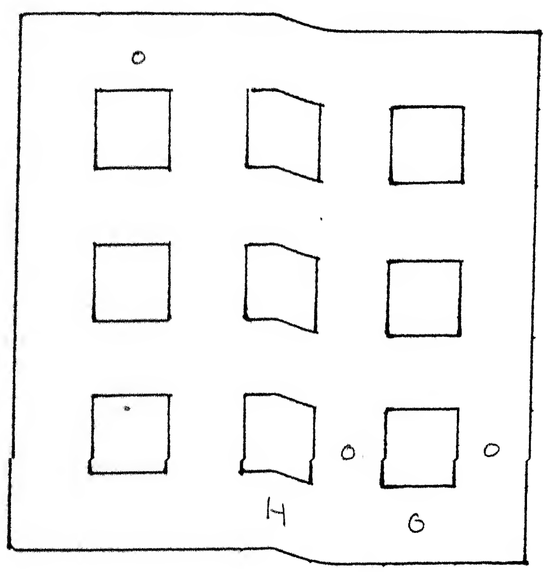


FIG. 3.20(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG. 3.20(b)



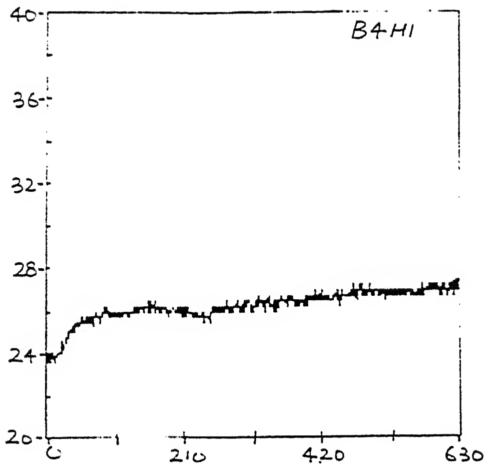
LEGEND

o TOP THERMOCOUPLES

x BOTTOM THERMOCOUPLES

H HEATER

FIG. 3.21(a) THERMOCOUPLE LOCATIONS FOR THE GRAPHS IN FIG. 3.21(b)



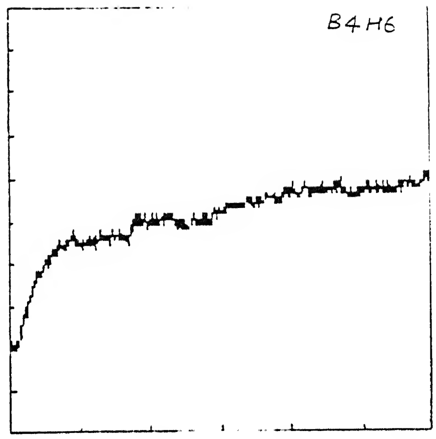
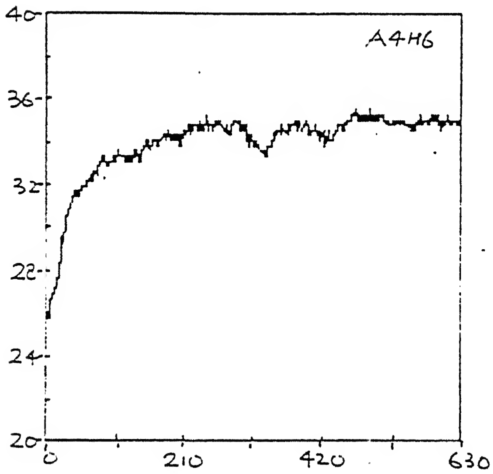
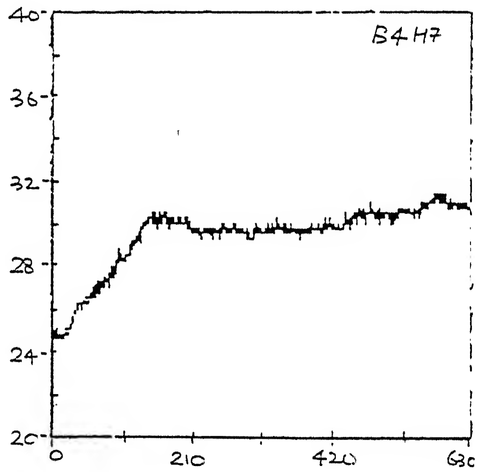
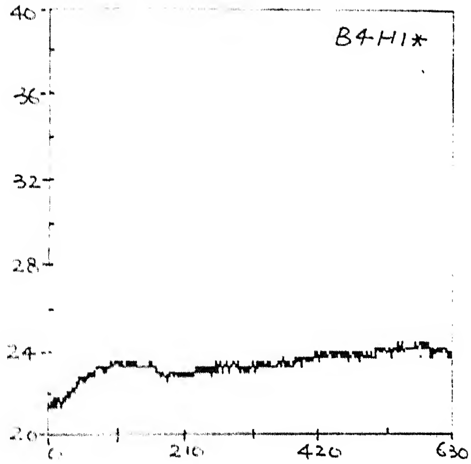


FIG. 3.20 (b)





X-AXIS: TIME IN SEC.
Y-AXIS: TEMP IN °C



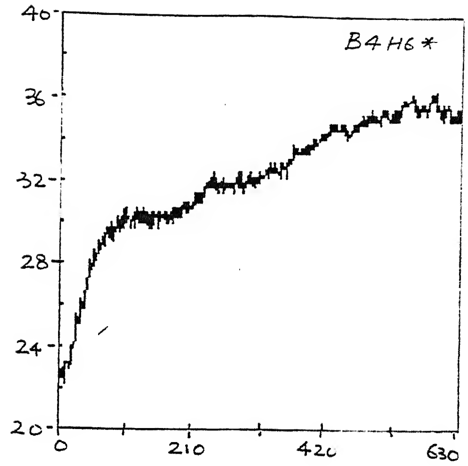
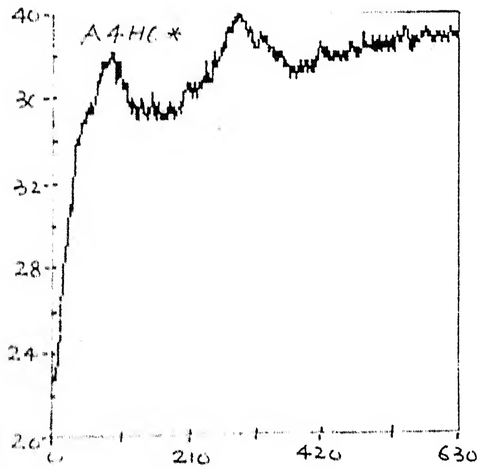
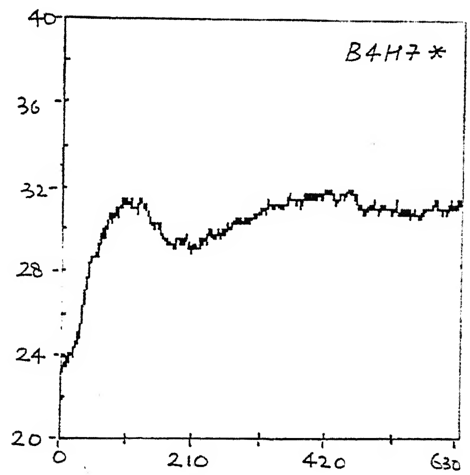


FIG. 3.21 (b)





X-AXIS: TIME IN SEC.

Y-AXIS: TEMP. IN °C

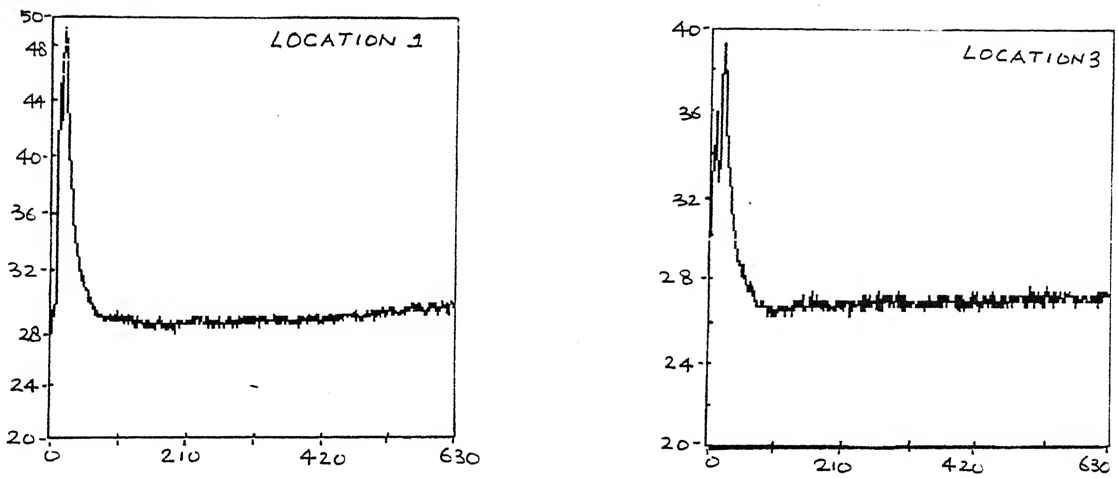
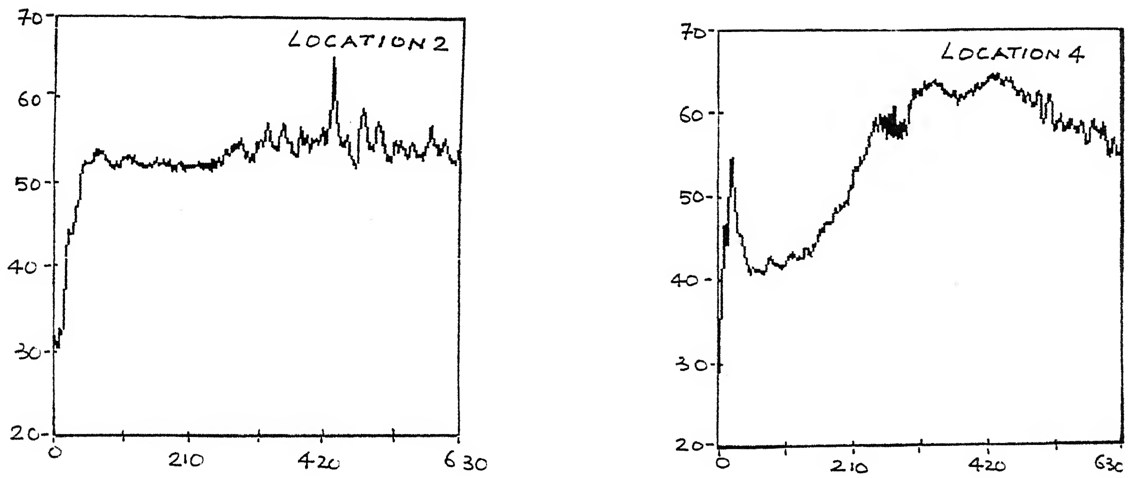


FIG. 3.22



X- AXIS : TIME IN SEC
Y- AXIS : TEMP. IN °C

temperature data recorded by thermocouples right above the heater for various input conditions. The graphs reveal a clear trend that the plume rises straight above the heater when two walls are presented on either side of the heater and attaches itself to the wall when only one wall is present. We believe that this trend is a consequence of the entrainment characteristics near the heater which will be asymmetric when only one wall is present.

3.7 RESULTS OF FLOW VISUALISATION

In the absence of clear photographs of flow visualization, the flow patterns were recorded manually by sketching them. Figure 3.24 shows these patterns. However, a representative photograph of the flow visualization is presented in Fig. 3.25,, showing the plume originating from the bunch of mosquito coils placed above the heater and rising above.

From flow patterns of Fig. 3.24, it is observed that plume divides itself into main branches whose number depends on the location of the heater. The flow enters other parts of enclosure by partial subbranching of the main flows. These results are in conformity with the trends concluded from the analysis of transient temperature data.

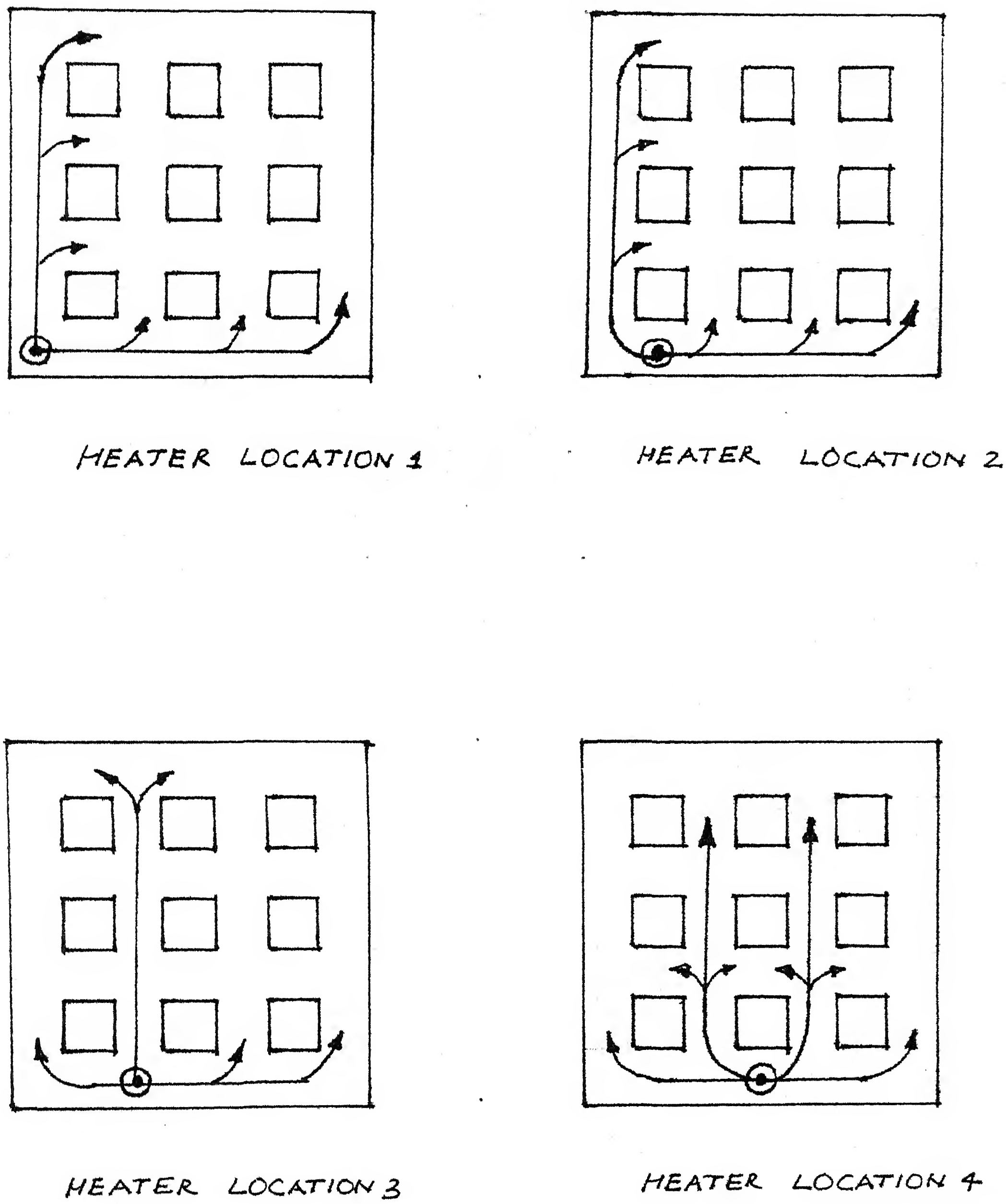
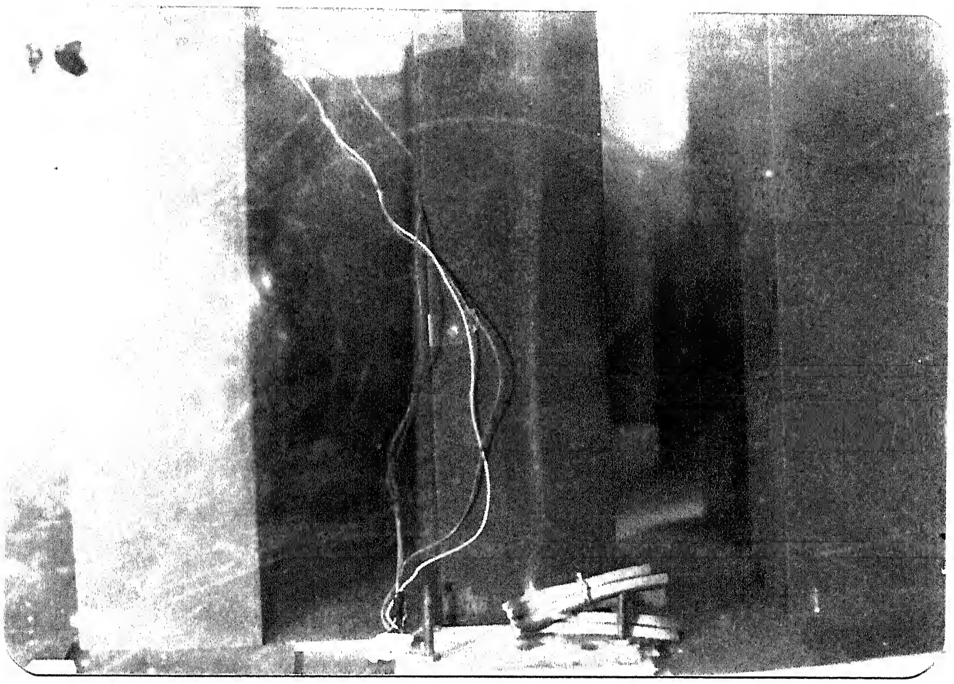


FIG 3.23 FLOW VISUALISATION PATTERNS



FLOW VISUALISATION

CHAPTER 4

CONCLUSIONS AND SUGGESTIONS

4.1 Present experimental study has led us to the following conclusions:

1. In the presence of localized heat source inside an enclosure, the plume affects only the top portion of the enclosure and on the contrary, bottom portion remains essentially unaffected. This is true for all heater locations, heating levels and aspect ratios considered during the study.
2. Distribution of plume at the top depends primarily on the heater location. During the study,it was found that plume divides itself into two, three or four main branches depending on the heat source position. Flow also enters the other passages between the pillars at the top from the main branches of the plume.
3. Large scale fluctuations in the local temperature at various places are found because of eddies which form part of the flow. These eddies are more dominant where the flow has to undergo a change in direction.
4. Walls of the enclosure play a vital role in the overall flow distribution. Plume from the heat source attaches itself to the wall in case the heat source has only one wall adjacent to it. When there are two walls, flow rises straight above the heat source without attaching itself to either of the walls.
5. Decrease in aspect ratio of the enclosure increases the overall temperature levels inside the enclosure due to less heat loss to the environment.

6. Roof of the enclosure has a crucial role in the overall heat loss from the enclosure to the environment. As the plume flows through the corridors, it loses heat through the top, resulting in progressively lower temperatures as the distance from the heat source increases.
7. Keeping the reference junctions of thermocouples submerged in ice water mixture is a successful way of boosting up the input signals to the PC.

4.2 SUGGESTIONS FOR FUTURE WORK

This area has potential for further study. Following are some suggestions in this regard:

1. Instead of thermocouples, RTDs (Resistance Temperature Detectors) can be used for stronger input signals.
2. Automatic control of heater plate temperature should be incorporated, avoiding the manual control of temperature.
3. Interior locations for the placement of heater and different configurations of the pillars should be tried in order to un derstand the phenomenon of spreading more closely.
4. An external amplifier to enhance the strength of the input signals from the temperature probes should be used and the cumbersome process of maintaining an ice junction should be avoided.
5. Temperature probes should be placed at more locations, especially near the corners and edges of the enclosure, in order to capture the phenomena of eddy generation.

6. Different sizes of plate heater should be tried for studying the effect of the size of heat source on the temperture distribution.
7. Possibility of plugging in more than one A/D card should be explored to avoid the time loss in repetition and associated errors.

REFERENCES

1. Cooper, L.Y., Mark, Broad M. and Quintiere, J., "An Experimental Study of Upper Hot Layer Stratification in Full Scale Multiroom Fire Scenarios", Paper No. 81-HT-9, 20 ASME/AIChE National Heat Transfer Conferences, 1981.

2. Cooper, L.Y., "Estimasting Safe Available Egress Time from Fires", NBS, NBSIIR 80-2172; 1981.

3. Cooper, L.Y., "Heat Transfer from a Buoyant Plume to an Unconfined Ceiling", Presented at the ASME/AIChE 20th National Heat Transfer Conference, 1981.

4. Eckert, E.R.G. and Carlson, Int. Journal Heat Mass Transfer, p. 106, 1961.

5. Elder, J.W., J. Fluid Mechanics, 23, p. 77, 1965.

6. Emmons, H.W., "The Prediction of Fires in Buildings", 17 International Symposium on Combustion, The Combustion Insdtitute, pp. 1101-1111.

7. Gebhart, B., Jaluria, Y., Mahajan, R.L. and Sammakia, B., "Buoyancy Induced Flows and Transport", Reference Edition, Hemisphere Publishing Corporation, 1988.

8. Globe, S. and Dropkin, D., J. Heat Transfer, 81, p.24, 1959.

9. Gnafakis, C., and Manno, V.P., "Transient Diistribution in a Rectangular Enclosure", J. Heat Transfer, 111, pp. 92-99, February 1989.

10. Hoult, D.P., Fay, J.A. and Forney, L.J., T. Air Pullot. Control Assoc., 19, p.391, 1969.

11. Jaluria, Y., 'Buoyancy Driven wall Flows in Enclosure Fires", The Combustion Institute, pp. 151-157, 1986.

12. Jaluria, Y., "Buoyancy Induced Wall Flows due to Fire in a Room", Nat. Bur. Stds. Report, NB SIR-84-2841, USA, 1984.

13. Karnavas, J.A., Kukuczka, G.A., Tracey, G.A. and Wojtyczka A., "Integration of Atmospheriic Inerting into Underground Mine Fire Fighting", Report J0328029 for US Department of Interior, Bureau of Mines.

14. Kooper, K. and Jaluria, Y., "An Experimental Study of the Generation and Characteristics of a Two Layer Thermally Stable Environment", Int. Comns Heat and Mass Transfer, 1988.

15. Kooper, K. and Jaluria, Y., "Heat Transfer from a Negatively Buoyant Jet", Int. J. Heat and Mass Transfer, 1988.

16. Kremnev, O.A. and Juravlenko, V.Y., "Heat and Mass Exchange in Rock Mass and the Underground Installations", kiev, Naukovata Dunka, p. 314, 1986.

17. Nansteel, M.W., Grief, R., "Natural Convection on Undivided and Partially Divided Rectangular Enclosures", J. Heat Transfer 103, pp. 523-629, 1981.

18. Quintiere, J., McCoffrey, B.J. and Kashiwagi, T.,"A Scaling Study of a Corridor Subject to a Room Fire," Combustion Science and Technology, 18, pp. 1-19,1978.

19. Quintiere, J.G., "An Approach to Modelling Wall Fire Spread in a room", Fire Safety Journal, 3, pp. 201-214.

20. Quintiere, J.G., Rinkinen, W.J. and Jones, W.W., Combustion Science and Technology, 26, pp. 193-201.

21. Ramsdell, J., "Variable Elimination in the Home Fire Code", ASME/AIChE National Heat Transfer Conference held at Milwankee, USA, 1981.

22. Rockett, J.A., "Modelling of NBS Matters Tests with the Harvard Mark V Fire Simulations", Fire and Materials, No. 2,pp. 80-95,1982.

23. Rockett, J.A. and Morita, M., "The NBS/Harvard Mark VI Multi Room Fire Simulation", Fire Science Technology, 5, pp. 159-164.

24. Rocket, J.A., "Two Approaches to the Analysis of Actual Fires", Fire Safety Journal, 9, pp. 17-28.

25. Silveston, P.L., Forsch. Geb. Ingenieurwesen, 24, p. 59, 1958.

26. Soberman R.K., J. Applied Physics, 29, p. 872, 1958.

27. Stemmphanov, T.P., "Interaction Between Temperatures of Air in the mine Workings and the Rock Walls Along the Length of Workings", III Plenary Session IBMT Plovdiv, USSR.

28. Starfield, A.M. and Blelock, A.L., "A New Method for the Computations of Heat and Moisture Transfer in Partly Wet Airways", J. of S.A. Int. of Mining and Metal, 83, 1983.

29. Stephanov, T.P., Arcenian, E.E. and Kalchev L.A., "Method of Predicting Non Stationary Heat Exchange Between Air and Walls in the Mine U.K.", IV Plenary Session IBMT, 1, pp 1-15, 1985.

30. Torrance, K.E., Orloff, L. and Rockett, J.A., "Experiments on Natural Convection in Enclosures with Localized Heating from Below", J. Fluiid Mech., 36, Part 1, pp. 21-31, 1969.

31. Van Heerden, C.A., "Problem of Unsteady Heat Flow in Connection with the Air Cooling of Collieries", Proc.

General Disc on Heat Flow London, Inst. of Mech. Engg., pp. 283-285.

32. Wacklawik, J., Miklajczyk, W. and Branny, M., "Flow of Air with Variable Density in Mine Ventilation Networks", Int. Journal of Rock Mech. Min. Sci. Geom. Abstr., Pt.23, No. 6.

33. Zukoski, E.E., "Heat Transfer in Unwanted Fires", Proceedings of 1987 ASME - JSME Thermal Engineeriing Conference, Honolulu, Cooper L.Y. and B.Farouk (Eds),1987